Mineral Nutrient Disorders of Root Crops in the Pacific

Proceedings of a workshop, Nuku'alofa, Kingdom of Tonga, 17–20 April 1995

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Research, Development and Extension Needs for Overcoming Nutritional Limitations of Root Crops in the Pacific: a Workshop Summary

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Abstract

Needs for continued work on the nutritional requirements of root crops were identified, particularly the diagnosis, prognosis and correction of nutrition disorders within the farming systems in which the crops are produced. Further work is needed also on the extension of research results, focusing on identifying and correcting local problems using means acceptable to farmers. Workshop participants recognised that good progress had been made in identifying visible symptoms of nutrition disorders of sweet potato (*Ipomoea batatas* (L.) Lam) and taro (*Colocasia esculenta* (L.) Schott), and recommended that this information be made available to agriculturalists of the region as soon as possible. Other crops on which similar research should be conducted include yam (*Dioscorea* spp.) and *Xanthosoma sagittifolium* (L.) Schott, and perhaps *Alocasia macrorrhiza* (L.) Schott and *Cyrtosperma chamissonis* (Schott) Merr. Overall, it was concluded that the identification and correction of nutrition disorders of root crops is an important factor contributing to sustainable farming systems in the Pacific.

THIS report summarises the views and observations of workshop participants on the priorities for future research, development and extension in root crop nutrition, particularly in relation to ACIAR Project 9101. The discussion was divided into four focus areas, each of which was introduced by a discussion leader followed by general contributions. (Discussion leaders were: Professor Jack Loneragan, Dr Malcolm Hazelman, Dr Steve Rogers and Mr Siva Halavatou; Dr Ramon de la Peña chaired the session.)

The importance of root crops in the region, as staple food sources, as major commodities for local commerce, and as export crops was reflected in the high priority given by Pacific country participants to the completion, distribution and implementation of the project findings.

Knowledge of nutrient requirements and management of sweet potato (*Ipomoea batatas* (L.) Lam) and taro (*Colocasia esculenta* (L.) Schott) still lags far behind that of crops such as maize (*Zea mays* L.) and even cassava (*Manihot esculenta* Crantz), while the nutrition of yam (*Dioscorea* spp.) has received very little attention. This discussion was intended to highlight the priorities, preferred processes for and perceived barriers to further development of tropical root crop nutrition.

Diagnosis and Prognosis of Nutrition Disorders

Considerable progress has been made in the area of diagnosis of nutrition disorders in taro and sweet potato, particularly in the use of visible symptoms to characterise problems. The main refinement required here is to verify the symptoms observed on

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glasshouse-grown plants with those found in the field. Field validation is also required in the area of plant tissue analysis. Records of tissue nutrient concentrations at various times during the growth of high-yielding crops would provide useful additional data.

Quick tests which can provide diagnostic answers in the field are highly desirable, especially for situations where laboratory analyses are not readily available. Leaf painting has been used successfully to demonstrate deficiencies of iron (Fe), manganese (Mn) and zinc (Zn) in sweet potato, and Fe in taro. Refinement is needed in the concentration of salts and wetting agents for elements other than Fe in taro. The area of sap testing has not been successfully developed in sweet potato or taro. A range of indicator test strips is available commercially for testing water for various nutrients. However, preliminary attempts to use these strips for analysis of taro and sweet potato sap were complicated by the heavy staining of the indicator strips by the sap. This has also been the experience with taro in Hawaii. Further work employing flocculants or the use of macerated plant tissue may overcome this problem.

The use of fertilizer strips to confirm field diagnoses, or to differentiate between a small number of possible or co-existing deficiencies, is a simple and informative qualitative technique which could be used more widely. For example, phosphorus (P), sulfur (S) and nitrogen (N) deficiencies were identified as potential limitations in a commercial taro nursery on Tongatapu. To evaluate the importance of these disorders, parallel strips of urea and ammonium sulphate, crossed by a perpendicular strip of triple-superphosphate, were recommended.

Colour-illustrated booklets containing diagnostic information for sweet potato and taro are being prepared, and are seen as a valuable resource for research and extension personnel throughout the region. The inclusion of diagnostic keys and instructions on the collection and preservation of leaf tissue for analysis, and on the use of leaf painting techniques and quick tests, where available, would greatly increase the utility of these publications. Where possible, information assisting the reader to distinguish between symptoms of nutrition disorders and those of plant pathogens and of herbicide injury would be helpful.

Prognostic tests, allowing the prediction of yield responses to soil amendments, are far less advanced than are the diagnostic plant tests, and pose different problems in their development. Both plant and soil tests need to be calibrated against crop yields. The development of prognostic soil tests is in progress in Tonga, and may provide a basis for extension of procedures to other regions. The role of vesicular arbuscular mycorrhiza (VAM) may complicate prognosis for P, and possibly also for Zn and copper (Cu).

Correction of Nutrition Disorders

The addition of nutrients to the soil, whether as chemical fertilizer, or in organic material, is essential for sustainable agriculture. Currently, there is little use of fertilizers by South Pacific farmers on root crops, even when they are grown as a commercial crop, and when the same farmer may be willing to use fertilizers on other 'cash crops'. There is a perception that traditional crops require only traditional management.

Where fertilizer recommendations have been made, they are often inappropriate NPK mixes, extrapolated from responses of other crops in other areas, or based on the availability of a particular commercial mix. There is a great need for properly calibrated soil tests to allow appropriate recommendations to be made. These must be cheap and quick, for effective amendments to be made. Where micronutrient deficiencies exist, they need to be recognised to allow efficient management of macronutrients. Often locally available materials (steel cans for Fe, galvanised iron pieces for Zn) can provide a simple and cost-effective source of micronutrients. Some low analysis fertilizers contain useful amounts of micronutrients as contaminants. It is important for farm advisers to be aware of such additional sources of micronutrients.

Organic materials, whether grown on the site or gathered from other areas, may be able to supply sufficient quantities of nutrients for the root crop, and may represent efficient use of local resources. The opportunity to take advantage of market premiums for organically-grown produce provides a further incentive to develop organic nutrient sources. In some areas, waste materials such as chicken manure and sugarcane pulp may be cheaply available, but supply of such materials will be localised. Some commercially available organic fertilizers represent poor value in terms of the nutrients they supply, compared with chemical fertilizers. Bringing fresh plant material from other areas is labour-intensive, and the nutrient export from the source area should also be considered. Growth of organic mulching material on the crop site, either as a green manure rotation or intercropped planting, may increase the availability of nutrients to the crop, but cannot add nutrients to the system other than N, and will not be effective in areas where, for example, a micronutrient deficiency remains uncorrected.

Attention is needed to the area of fertilizer use efficiency. Identifying which nutrients are limiting is the first step. Within ACIAR Project 9101, progress is being made in identifying nutrient limitations of root crops on some major soil types in the region. Maximum benefit requires optimisation of the form of nutrient source, time of application and placement. Soils with high P-fixing capacity need to be recognised and managed appropriately. The widespread deficiency of P in Tongan soils was overlooked for many years, as fertilizer trials had never employed rates of P high enough to obtain a yield response. The probability of water stress or disease incidence reducing the ability of the crop to utilise added nutrients is an important economic consideration in many areas. Organic materials, in addition to their nutrient contributions, may be effective in increasing the availability of P fertilizers in high P-fixing soils, and in conserving soil moisture. Organic matter may also ameliorate problems relating to low soil pH. While trials have tended to compare the separate effects of organic and chemical soil amendments, there is scope for better integration of these resources.

With the introduction of new management practices, environmental impacts such as increased nitrate or P levels in water supplies need to be anticipated and monitored, bearing in mind other sources of contamination such as sewage and detergents.

Other Crops

Yam is a crop of great cultural significance in the region, and a major food source in many areas. It is recognised by farmers to have a high nutrient requirement, being planted first in the cropping cycle. However, little work has been done on the nutritional requirements of yam. The value of a systematic study of nutrition disorders of yam was raised a number of times throughout the workshop, and was identified as a priority for future research.

Yam had been included in the original proposal for ACIAR Project 9101. It was decided, however, to exclude this crop to ensure that the proposed program was achievable, rather than because it was perceived to be of less importance than taro or sweet potato. As several species of yam (including *Dioscorea alata* L., *D. esculenta* (Lour.) Burk. and *D. nummularia*) are used throughout the region, the research required to characterise nutrient responses in each species may be more involved than for taro or sweet potato.

While it is not feasible to include yam in an extension of ACIAR Project 9101, if a future project were to be supported, it would be best to take advantage of the expertise in the current project through continuity with it. Sufficient advance notice would allow plant material of appropriate cultivars to be assembled, gaining a considerable time-saving within the new project.

Xanthosoma sagittifolium (L.) Schott is an increasingly important crop in the area, but has been little studied. The intention to include it in the current study of *Colocasia* taro was made impractical due to difficulties in obtaining and multiplying plants in Brisbane. However, there is scope to include it in an extended phase of the project, if this is seen to be a priority. Views were expressed that this was desirable, as *Xanthosoma* has a significant ecological and cultural place in the suite of root crops grown in the region, distinct from that of *Colocasia* taro. Additionally, the devastating effect of taro leaf blight (*Phytophthora colocasiae*) in Western Samoa has rapidly increased the importance of *Xanthosoma* in that country since 1993. Symptoms of nutrient deficiencies appear to differ between *Xanthosoma* and *Colocasia*, so specific characterisation would be valuable.

Characterisation of symptoms in additional cultivars of sweet potato and taro was seen as having lower priority, given the common trends identified among the cultivars compared to date. However, the possibility of screening genotypes for adaptation to specific nutrient limitations may be of considerable benefit, as has been shown for many other crop species.

The importance of *Alocasia macrorrhiza* (L.) Schott and *Cyrtosperma chamissonis* (Schott) Merr., the latter particularly in the atolls, was raised for possible future consideration.

Farming Systems

Research on root crop production systems in the region has largely focused on the management of trees for providing surface mulch, soil organic material, N and controlled shade for interplanted taro. The substitution of grass fallow with a leguminous cover crop has also been evaluated. More information is needed on the effects of these practices on crop production, and on the use of other crops (e.g. maize) as indicator species for nutrition disorders of associated root crops.

Benefits of Networking

There is a need for greater cooperation among scientists, and a better integration of research with extension and policy formation. At present, research institutions tend to keep to themselves. Cooperation needs to go beyond lip-service and some work on experiments of others. There is a great opportunity to share expertise.

Those responsible were congratulated for organising the workshop, and it was stated that 'this workshop has been an excellent example of inter-agency, inter-country, and interdisciplinary cooperation'. Resources are rarely made available for cooperative technical meetings. Regional organisations such as the South Pacific Commission have a role in coordinating efforts, but difficulties often lie in getting the appropriate individuals together. The taro meeting to be convened by SPC in June provides a good example of the demand for regional and interdisciplinary links. The meeting was originally intended for pathologists, especially focusing on taro leaf blight, but through wider expression of interest has expanded to include other issues of crop protection and agronomy. The establishment of a taro network will be discussed.

The idea of networking received general support from workshop participants. Initiation of cooperative links depends on the agriculturalists working in the area knowing of the work being done by others. Many workshop participants were neither aware of the various organisations that exist, nor of their specific roles. Further, procedures for approaching the organisations were not known. A network could make up-to-date information widely available.

Better networking is desirable in the context of ACIAR's mode of operation. Where possible, ACIAR prefers to support partnerships which focus on programs already underway in the region, conducting strategic research on problems that the region has identified as important.

There is also a need for scientists to influence policy relating to agricultural production and land management: important policy areas include the availability of appropriate fertilizer mixes, the use and management of trees and determining who pays for externalities such as environmental impacts.

Extension of Research Results

The relationships among researchers, extension workers and farmers are complex. Many perceptions, beliefs and values affect the importance attached to the various roles. To consider the interactions only among these three groups is an oversimplification, because suppliers and purchasers, politicians and policy-makers all influence the nature and impact of information transferred.

There is a need to create opportunities for communication, both from and to researchers. Structural constraints must be reduced to allow information to flow freely among individuals. However, even multidisciplinary teams can have communication problems; team members may be compartmentalised in roles, for example, the farmer may become merely the plot weeder for an on-farm trial.

With regard to the outputs of ACIAR Project 9101, the colour booklets in preparation are seen to have great potential value. However, careful thought should be given to the format and language of the publications, and the inclusion of enough instructive material on the use of diagnostic techniques and possible corrective measures. While the booklets may not be accessible to farmers in many cases, the distribution of posters on disorders of particular importance could make key information widely accessible to them. Posters could also be produced easily in a range of languages.

In many areas, there is a problem of farmers not accepting recommendations from research. There is a need to develop methods of implementation tailored to meet the local problems and barriers. Strengthening the capabilities of extension personnel through resources, training and continuing communication is a key area. Funding for extension officers to attend regional scientific meetings should be encouraged. Since 1992 ACIAR had a mandate to support an extension phase of projects, and also to encourage the training of scientists associated with its projects.

Conclusions

Sustainable crop production, including environmental and economic considerations, is dependent inter alia on good nutrient management. This involves both nutrient conservation and the judicious application of nutrients in short supply, ensuring root crops with high yield (although not necessarily maximum yield) and high quality. In most farming systems, root crops are managed with low inputs, and hence good financial returns might be expected for relatively low inputs of fertilizer. This is provided, of course, that the nutrients supplied are those which are in short supply. Numerous techniques exist for the diagnosis of nutrition disorders which occur as local problems, although optimal correction of these disorders remains a problem, given the diversity of farming systems and variation in soils and climate.

Given the difference between root crop yields obtained in practice and the maximum yields possible for both sweet potato and taro, considerable scope exists for improving farm yields. Poor nutrition is regarded as one of the reasons for poor overall yield, but the extent of yield depression needs to be ascertained in relation to other yield-limiting factors (e.g. drought, weeds). Even on soils perceived to be highly fertile, as on Tongatapu, nutritional limitations to the growth of maize have been shown to be widespread. A great need remains to identify the extent of nutrition disorders of root crops in existing farming systems, and to develop means that are acceptable to farmers of correcting these disorders.

Diagnosis of Nutrient Disorders and their Management

J.F. Loneragan[1]

Abstract

This paper briefly reviews diagnostic and prognostic procedures used in nutrient management. Symptoms are valuable in signalling nutrient disorders. Field trials are essential for confirming the disorders and for providing definitive data on all nutrient limitations to crop production and the levels of fertilizers or ameliorants required to correct them. Field trials also provide standards for correlating crop response to plant and soil analytical procedures, for more rapid and convenient assessment of the nutrient status of crop response on similar soils over wide regions.

OPTIMAL crop production requires careful nutrient management. Where fertilizers are expensive relative to crop value, the use of minimal quantities of fertilizers while avoiding severe nutrient deficiencies is indicated. Where fertilizers are cheap relative to crop value, fertilizer applications should guarantee optimal nutrition while avoiding nutrient toxicities and pollution of ground waters.

The contrasting needs of both nutrient strategies can be met by information on the nutrient status of soils and crops, related to the quantity of crop product. For pastures, the product is herbage mass of high digestibility and nutritional quality throughout the year. For cereals, it is grain weight and protein at maturity. For sugar cane and sugar beet, the product is extractable sugar. For tropical root crops, the product is the tuber or corm mass and the criteria for quality vary with end-use but may involve size, texture, flavour, and storage behaviour.

Plant tests are available for diagnosing the nutrient status of crops at the time of examination and sampling. Many have also been used for prognosis of nutrient status at harvest, i.e. for predicting, from sampling during crop growth, whether nutrients will affect crop product at harvest. Soil analyses are also used extensively for predicting crop response to fertilizers and as a guide to nutrient management.

When used for diagnostic purposes, tests can provide definitive answers on the nutritional status of the plant at the time of sampling. But when used for prognosis, tests can never be definitive. They can only predict that nutrients will be deficient, adequate or toxic at harvest as a probability dependent on other factors following sampling, including seasonal conditions, pests, diseases, and soil nutrient supply. This fundamental limitation to prognostic tests must be recognised to avoid unrealistic expectations of them.

This paper looks briefly at the principles underlying the diagnosis and management of nutrient disorders. For details of the techniques and their application, consult the extensive literature (Bergmann 1983; Reuter and Robinson 1986; Westerman 1990).

Fertilizer Response Trials

Standard procedure for defining nutrients likely to be deficient in a soil for crop growth is to undertake soil fertilizer trials in the field or in pots. The best experimental design varies with the information available and the number of deficiencies likely to limit growth. But all designs must recognise the over-riding principles first stated nearly 200 years ago by Sprengel and Liebig in the 'Law of the Minimum' ('supplying a plant with a nutrient which is deficient will not increase its growth if another nutrient is more limiting') and later refined by Blackman (1905) in his 'Law of Limiting Factors' ('the effect of a factor is least when another factor limits growth and greatest when all other factors are in optimal supply'). Hence, any test for a soil nutrient

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deficiency is only definitive when the soil contains optimal amounts of all other nutrients. Figure 1 illustrates this principle dramatically for the production of wheat grain on a soil deficient in four nutrients. Although the soil was very nitrogen-deficient, wheat responded to nitrogen fertilizer only when phosphorus (P), copper (Cu) and zinc (Zn) fertilizers were also added; indeed, adding nitrogen fertilizer together with only two of these three other fertilizers actually depressed yields below that of plants given no fertilizer at all.

Since addition of at least 14 of the 16 or 17 known essential soil nutrients has increased crop production in some soils and since several may be deficient on a single soil, diagnosis of nutrient deficiencies can be very complex. Variability of plant genera, species and cultivars' susceptibility to deficiencies further complicates diagnosis. But with proper recognition of the *Law of Limiting Factors*, good research programs can quickly simplify most diagnostic problems within regions by identifying the nutrition deficiencies likely to occur in particular crops on specific soils.

Where only one or two nutrients are deficient, a factorial combination of all nutrient fertilizers is a powerful experimental design. But where three or more nutrients are limiting, it is less useful, and a subtractive or omission fertilizer trial may be better. In the omission trial, control plots receiving all nutrients are compared with treatment plots which receive all nutrients except one or a small group (Loneragan 1970).

While quite simple in concept, fertilizer trials often fail. Sometimes the basal fertilizer is incomplete or suboptimal. In some cases, it may be necessary to test levels of some fertilizers before undertaking a general diagnostic trial, e.g. the level of phosphate or borate fertilizer application appropriate to overcome a deficiency on a heavy clay soil may be toxic on a light sandy soil.

Micronutrient deficiencies are especially difficult to diagnose in fertilizer trials because of the tiny amounts required for plant growth and the ease of contamination from macronutrient salts, seeds or work procedures.

Contamination from micronutrients in fertilizers presents an especially difficult problem. For example, commercial superphosphate, gypsum and NPK fertilizers in Thailand were so heavily contaminated with micronutrients that they could not be

Fig. 1. Response of wheat to nutrients on a sand deficient in nitrogen, phosphorus, copper and zinc. Plants responded poorly or not at all unless all four deficient nutrients were added together (ALL).

used as basal fertilizers in field trials for diagnosis of micronutrient deficiencies in legume crops (Bell et al. 1990). The problem has been compounded by variability in the level of contamination in supposedly identical fertilizers from different sources. In Australia, zinc contamination of basal superphosphate has obscured zinc deficiency in field trials causing problems when phosphatic fertilizers of low zinc content were used subsequently on the same soils (Loneragan 1970).

High levels of micronutrients in seeds have obscured micronutrient deficiencies in soil as observed for boron in black and green gram in Thailand (Rerkasem et al. 1990). Seeds may contain sufficient molybdenum (Mo) (Meagher et al. 1952) and cobalt (Co) deficiencies (Robson and Mead 1980) to supply the plant's full needs even in very deficient environments: trials using seeds from non-deficient areas may fail to diagnose Mo and Co deficiencies in soils which are severely deficient for a farmer's crop sown with seed from his previous crop on the same soil. Similar problems are likely to be encountered in experiments with root crops where the micronutrient content of propagules from plants raised on fertile soils could be sufficient to obscure deficiencies in experimental soils. Such problems can be avoided by analysis of propagule material prior to planting or by using propagules from plants grown in untreated experimental soil.

Contamination from pesticides, fungicides and poor cultural procedures may also obscure micronutrient deficiencies in trial plots. Researchers need to be continually aware of potential problems such as those encountered in early studies of 'pecan rosette' disease which was cured by iron sulfate sprays. Later studies showed that iron sulfate was effective only when sprayed from galvanised buckets which released sufficient Zn to correct what proved to be Zn deficiency (Alben et al. 1932 a,b).

Correction of nutrient deficiencies requires information on optimal fertilizer rates which need to be established by fertilizer rate trials in field experiments.

Unfortunately, field tests are time-consuming, expensive in technical expertise and subject to environmental hazards. Pot trials with the surface horizon of field soils overcome some of these problems and may be used to supplement field trials; for micronutrients, they introduce additional sources of contamination from water and the environment. But both field and pot trials are slow and provide little or no information of value to the current season's crop. Consequently, there is a need for quicker, less demanding procedures to provide information in time to correct nutrient deficiencies early in crop life or to be used in surveys to define deficiencies likely to occur on particular soil types.

Despite their problems, field trials provide the standard data for calibration of all other tests and are essential components of any nutrient research program.

Symptoms

Symptoms can be very useful guides to nutrient problems. They are especially useful in low input agriculture. For high input agriculture, they have the disadvantage that, by the time symptoms appear, yield may already have been depressed severely (Reuter et al. 1981 a.)

In a few cases, symptoms are sufficiently specific to allow definitive diagnosis of particular deficiencies. For example, the symptom of 'hollow heart' in seeds has been used for the diagnosis of boron (B) deficiency in peanuts and for mapping areas of B deficiency in farmers' peanut crops (Netsangtip et al. 1985; Bell et al. 1990). Many other nutrient deficiencies give symptoms which are sufficiently distinct to allow trained observers to diagnose problems in specific crops in regions where they are familiar with soil types; good descriptions with colour photographs help (Asher et al. 1980; Snowball and Robson 1986; Grundon et al. 1987; Asher 1992).

Symptoms may also give strong leads to toxic soil conditions: manganese (Mn) toxicity symptoms have been described for many crop plants (Bergmann 1983) and stunted root growth often indicates excess acidity and aluminium (Al) (Asher et al. 1980).

Diagnosis of nutrient deficiencies from symptoms should be confirmed by response of the crop to nutrients. Observing the recovery from symptoms of leaves painted with nutrient salts or crops treated in strips with fertilizers can provide quick and simple confirmation of a suspected deficiency.

Concentrations of Total Nutrient

Diagnosis of nutrient deficiencies based upon the concentration of nutrients in dried plant samples is the most widely used of all diagnostic tests. It has the advantages of easy sample collection and preservation for transport to analytical laboratories. Recent development of equipment for rapid, multi-element analysis of small amounts of nutrients and for computer processing of data also allow for the processing of many nutrients from a single sample; it has expanded greatly the potential and popularity of these tests (Handson and Shelley 1993).

The use of nutrient concentrations for diagnosis is based on the assumptions that a minimum concentration of each nutrient is necessary for plant growth or product, that lower concentrations are deficient and depress growth, that higher concentrations up to a limit are adequate or luxurious and sustain maximum growth, and that above that limit they are toxic and depress growth (Fig. 2). It assumes further that the minimum or 'critical' concentrations for deficiency and toxicity are constant for any plant cultivar and thus uniquely define its nutrient status.

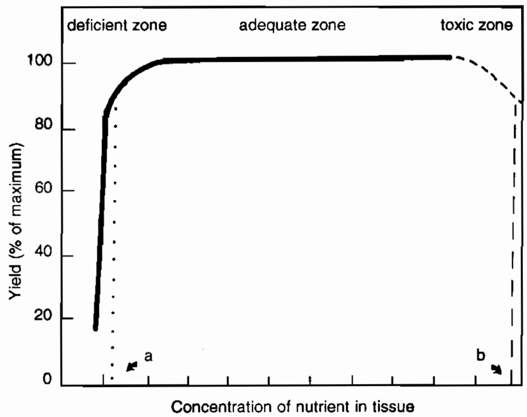

Fig. 2. Relationship of plant yield to nutrient concentration in plant tissue. The letters a and b indicate the critical concentrations for deficiency and toxicity respectively at 90% maximum yield. (Ulrich and Hills 1967).

While these assumptions have often failed, they have proved sufficiently valid under defined conditions to have made the procedure a valuable aid to deficiency diagnosis and fertilizer management. Factors responsible for failure and the procedures recommended for success are discussed briefly below

Nutrient concentrations in whole plant shoots have often proved unsatisfactory because their critical levels for most nutrients change with plant age. For mobile nutrients such as nitrogen (N), P, and potassium (K) which move rapidly from older leaves to young organs with the onset of deficiency, critical concentrations decrease as plants age and the proportion of older tissues increases. For immobile nutrients such as B, calcium (Ca) and Mn, critical concentrations may increase with plant age as older leaves retain high nutrient concentrations even during the onset of deficiency in meristem and young tissues (Loneragan 1968). For variability mobile nutrients such as sulfur (S) and Cu, the relationship of critical concentrations in whole tops to deficiency varies greatly with N supply which controls their release from old leaves to new tissue (Loneragan et al. 1976; Hill et al. 1978).

The relationship of nutrient concentrations in whole plant shoots to growth or yield is sometimes unsatisfactory because the concentration of nutrient in a severely deficient plant exceeds the critical concentration for deficiency diagnosis. The resulting C-shaped curve is know as a Piper-Steenbjerg curve after early observers of the phenomenon (Loneragan 1978).

Some workers have overcome these problems by relating nutrient concentrations in whole tops to plant development and sampling at well-defined growth stages (Andrew and Robins 1969; Andrew 1977). For the mobile nutrients, the relationship obtained with these procedures may apply to a wide range of soil and climates. For other nutrients they will vary with local soil conditions due, in the case of immobile nutrients, to differences in the supply of the test nutrient and, in the case of variably mobile nutrients, of N.

For all nutrients, concentrations in specific plant parts of similar physiological age generally give better and more consistent relationships to nutrient status than concentrations in whole plant tops. For example, as subterranean clover plants aged from 26 to 98 days, the critical concentrations for diagnosis of Cu deficiency remained relatively constant at 3 mg Cu/kg in the youngest open leaf but decreased progressively from 4 to 1 mg/kg in whole shoots (Reuter et al. 1981 b)

The youngest fully expanded leaf (YFEL) is recommended for many nutrients in many species (Ulrich and Hills 1967; Reuter and Robinson 1986). But for some nutrients in some species, other leaves or plant parts are more sensitive — for Cu, the shoot tip in peanuts (Robson et al. 1977) and young leaves in subterranean clover (Reuter et al. 1981 b); for Zn the youngest open leaf in subterranean clover (Reuter et al. 1982); for Mo, the nodule or the leaf blade below the YFEL in green gram (Jongruaysup et al. 1994). Nevertheless, for most nutrients and crops, concentrations in the YFEL provide a sufficiently good guide to be used for deficiency diagnosis where a single sample is collected for multi-element analysis.

Choosing a suitable plant part often presents more difficulties for perennial than for annual crops owing to massive movement of nutrients associated with fruit development and leaf fall and the impact of nutrient deficiencies in one year on crops in subsequent years (Reuter et al. 1993; Robinson 1993).

Diagnosis of K deficiency also presents special problems in those species in which sodium (Na) and other cations can partially replace K. Defining the critical concentrations of K required for different plant functions and the extent of its ability to be replaced by Na may resolve this problem (Barraclough and Leigh 1993).

The critical concentration of a nutrient is determined by correlating nutrient concentration of a selected plant part with some measure of response of plants grown in an environment containing a series of levels of test nutrient and adequate levels of all other nutrients; it is generally defined as that concentration at which plants achieve 90% of their maximum shoot dry matter. But in some experimental systems other more sensitive measures of response are required because dry matter responds too slowly to the onset of deficiency (Spear et al 1978; Nable et al. 1984; Kirk and Loneragan 1988).

Other Diagnostic Tests

Physiological activities, metabolite concentrations, enzyme activities and concentrations or ratios of all or selected forms of nutrients in living and dead plant parts and expressed sap have all been used for diagnosis (Bouma 1983; Smith 1986). Like the concentration of total nutrients, these parameters can only be used after correlation with some measure of plant response.

Many of these tests are valuable for checking on the nutrient status of individual nutrients as, for example, the lignin staining (Bussler 1981) and ascorbate oxidase (Delhaize et al. 1982) tests for Cu deficiency. They are especially powerful where inactive enzyme from a deficient plant is reactivated by addition of the deficient nutrient, as when Mo is added to nitrate reductase from Mo-deficient wheat (Randall 1969). Enzyme tests may also provide the basis for ELISA (enzyme-linked immunosorbent assay) tests as several authors have recently shown (e.g. Rao and Ownby 1993).

Some of the tests, including the two above for Cu, can also be done quickly on fresh tissue in the field. Rapid, simple tests for determining nutrient concentrations in sap expressed from petioles or leaves are gaining popularity, especially the determination of nitrate as a measure of N status which works well in some situations (e.g. Ulrich and Hills 1990; Williams and Maier 1990; Elliott et al. 1993) but not in others (Scaife and Turner 1987).

While many of these tests are excellent for diagnosing individual nutrient deficiencies, they are not as suitable for assessing toxicities or surveying the status of a wide range of nutrients as is the determination of total nutrient concentrations in dried plant material.

Prognostic Plant Tests

Prognostic tests have the decided advantage that they permit corrective action to be taken following sampling and so avoid loss of production at harvest. Their disadvantage is the variability arising from the operation of various factors following sampling. For example, Hannam et al. (1985) developed a prognostic test which predicted that *Lupinus angustifolius* with Mn stem concentrations of greater than 20 mg/kg at anthesis would not develop Mn deficiency in mature seed; with less than 20 mg/kg Mn they would become Mn-deficient unless rain fell or they were sprayed with Mn solutions after sampling. Hence the test allows farmers to decide in the context of their financial circumstances whether to incur the cost of spraying or risk losing production if rain is inadequate.

Most of the tests developed for diagnosis have also been used for prognosis. Critical values for both diagnostic and prognostic purposes are often determined in the same experiment by relating plant properties measured at intervals during growth to plant yield at sampling and at maturity (e.g. Jongruaysup et al. 1994). These values should be useful where a plant does not store utilisable reserves in some other plant part. But where it does, the part most suited for diagnosis will not be suitable for prognosis unless it gives an estimate of the plant's store of translocatable nutrient reserves. In the study of Mn deficiency in lupins mentioned above, stems were chosen for prognosis because they accumulated Mn and, in contrast to leaves, retranslocated it readily (Fig. 3). Young leaves were recommended for diagnosis because their Mn concentration responded quickly to low external Mn supply.

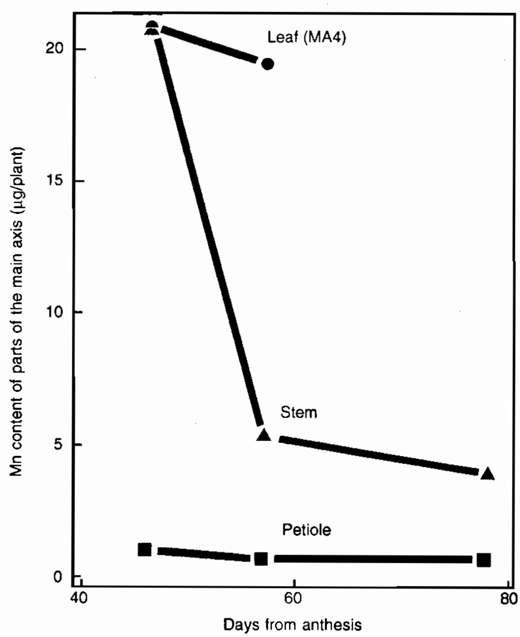

Fig. 3. Manganese contents of the petiole and blade of the fourth leaf and the stem of the main axis of *Lupinus angustifolius* during seed development and after termination of external manganese supply. (Data of Hannam et al. 1985).

More pragmatic approaches have used nutrient concentrations of high-yielding crops to provide ranges of concentrations considered desirable. A variant on this approach, DRIS (diagnosis and recommended integrated system), converts nutrient concentrations into ratios which are used to calculate nutrient indices considered desirable (Walworth and Sumner 1987). Extensive data from high-yielding crops are required to establish DRIS indices and their predictive power has yet to be shown to be substantially better than traditional, less demanding, procedures. Moreover, contrary to early claims of general validity, DRIS indices have been shown to vary with location and time of sampling (Jones 1993).

For high value crops, nutrient concentrations may be monitored throughout growth, and maintained within optimal ranges by applying fertilizers. The practice is best known in the 'crop logging' of sugar cane in Hawaii where Clements has set critical concentrations of nutrients in relation to climate and physiology for sugar production in a 24-month crop cycle (Bowen 1990). A similar approach to sugar production from irrigated sugar beet in California has emphasised the importance of monitoring nitrate concentrations as a guide to the fertilizer practice and harvest time (Ulrich and Hills 1990).

But to the extent the application can be made of nutrient concentrations for prognosis of nutrient disorders from specific situations to general application to crops on a wide range of soil types, information on nutrient concentrations in plant parts must be supplemented by additional information on the capacity of soils to supply the test nutrient following sampling of the plant.

Prognostic Soil Tests

Soil analyses are potentially the most useful of all prognostic tests as, if successful, they can provide information in time to take corrective action at the time of sowing a crop. As for plant analysis, they are useful only after calibration against plant response.

For macronutrient fertilisation of low to medium value crops, soil analyses are needed for prediction of optimal yields at minimal fertilizer costs. A lower level of precision would generally be acceptable for micronutrient fertilisation in the same crops and for all nutrients in high value crops. In these cases recommendations should provide adequate nutrients while avoiding toxicities to crops and pollution of surface and ground waters.

With the exception of N, the total amount of nutrient in a soil seldom relates to its adequacy for plant growth. Soil organic matter contains almost all soil N and is the most common index of N availability to crops, subject to various adjustments to take into account its rate of decomposition and losses from the soil from leaching and other processes (Dahnke and Johnson 1990). For other nutrients, the concentration and ability for replenishment in the soil solution (i.e. nutrient intensity and capacity) are generally far more important than the total amount in the soil. But the procedures for measuring capacity are too long and complex for easy inclusion in routine soil analysis. Laboratories therefore extract nutrients from soils by various methods and relate their concentrations to plant growth. Unfortunately, no single extraction method is satisfactory for all nutrients although increasing use is being made of multi-element extractants (McLaughlin et al. 1993).

Various soil properties, such as pH and content of clay and organic matter, modify the relationship of plant growth to nutrients in the soil extract. Unless their influence can be taken into account, any interpretation of the soil data must be restricted to soils whose extractable nutrient concentrations have been related directly to plant growth. Interpretation must be further restricted to the specific cultivars of crops which have been tested, since there are large variations among species, and even among cultivars within species, in their response to both deficient and toxic levels of nutrients in soils (Graham 1984).

Given these limitations to the successful interpretation of soil analyses, it is not surprising that soil analysis is most popular in regions where a particular crop has been grown for many years over large areas of relatively uniform soils. Transfer of the techniques from such regions and crops to new regions or crops requires careful checking against good field experiments. Nevertheless, soil analysis has sometimes proved useful as a guide to likely nutrient problems for crops or soils which have received little nutrient research attention.

Correction of Nutrient Disorders

Nutrient problems can sometimes be solved by changing the crop cultivar or, if this is not possible, growing an alternative crop (Graham 1984).

Organic residues or cover crops incorporated into the soil are important nutrient sources in some agricultural systems. Leguminous crops are especially important for providing N.

Where these procedures are not available or fully effective, fertilizers or soil ameliorants must be applied. Macronutrient fertilizers are generally placed near propagules at sowing or topdressed; proper placement is particularly important for correcting phosphorus deficiency on soils with high capacities to sorb phosphate. Micronutrients may also be supplied as fertilizer salts to the soil but problems arise from the difficulty of distributing evenly the small amounts required and from toxicity of oversupply. Careful mixing of micronutrients into macronutrient fertilizers has allowed safe application of micronutrients to soils and corrected most deficiencies for many years; these fertilizers have been less successful in correcting Mn and iron (Fe) deficiencies on calcareous soils due to rapid reactions in soils rendering Mn and Fe unavailable.

Micronutrient deficiencies in a current crop may also be corrected with foliar sprays as already mentioned for Mn deficiency in *Lupinus angustifolius*. They may also be prevented from developing by treating propagules or seedlings with potentially deficient micronutrients before sowing, as has been done by dipping potato seed pieces in or watering cauliflowers in seed beds with Mo solutions (Waring et al. 1948; Bear 1954), pelleting seeds of pasture legumes with Mo (Kerridge et al. 1973) and dipping rice seedlings in suspensions of zinc oxide (Katyal and Ponnamperuma 1974). These procedures have special potential for application to tropical root crops which are sown with propagules large enough to retain appreciable amounts of micronutrients and to be easily treated in nurseries or during planting.

For all micronutrients except iron, simple fertilizer salts are as effective in correcting deficiencies as any of the many expensive proprietary formulations available in the market. The efficacy of micronutrient salts in foliar sprays is enhanced by detergents, but the concentrations of detergents and micronutrient salts must be kept non-toxic. Chapman (1966) gives many valuable references for various micronutrient treatments. Fe salts are exceptional because of the instability of ferrous salts and the insolubility of ferric hydroxide. Chelate complexes which keep Fe in solution have been very effective in correcting recalcitrant Fe deficiency, especially on calcareous soils (Chen and Barak 1982).

Where dressings of fertilizers or ameliorants are required, information is needed from field trials on appropriate rates in relation to crop value, seasonal conditions and likely pollution problems. Where sufficient data have been accumulated, recommendations for fertilizer or ameliorant applications have been refined by integrating nutrient information with other factors into computer models (Angus et al. 1993).

References

Alben, A.O., Cole, J.R. and Lewis, R.D. 1932a. Chemical treatment of pecan rosette. Phytopathology, 22. 595–601.

— 1932b. New developments in treating pecan rosette with chemicals. Phytopathology, 22. 979–980.

Andrew, C.S. 1977. The effect of sulphur on the growth and nitrogen concentrations, and critical sulphur concentrations of some tropical and temperate pasture legumes. Australian Journal of Agricultural Research, 28. 807–820.

Andrew, C.S. and Robins, M.F. 1969. The effect of phosphorus on the growth and chemical composition of some tropical pasture legumes. I. Growth and critical percentage of phosphorus. Australian Journal of Agricultural Research, 20. 665–674.

Angus, J.F., Bowden, J.W. and Keating, B.A. 1993. Modelling nutrient responses in the field. In: Barrow, N.J., ed., Plant Nutrition — from Genetic Engineering to Field Practice. Dordrecht, Kluwer Academic. 59–68.

Asher, C.J. 1992. Diagnosis and correction of nutrient limitations to food crop production: the need for additional research on the tropical root crops. Journal of South Pacific Agriculture, 1. 83–88.

Asher, C.J., Edwards, D.J. and Howeler, R.H. 1980. Nutritional Disorders of Cassava, Brisbane, University of Queensland. 48 p.

Barraclough, P.B. and Leigh, R.A. 1993. Critical plant K concentrations for growth and problems in the diagnosis of nutrient deficiencies by plant analysis. In: Barrow, N.J., ed., Plant Nutrition — from Genetic Engineering to Field Practice. Dordrecht, Kluwer Academic. 245–248.

Bear, F.E. 1954. Trace elements: progress report on research, with particular reference to New Jersey soils. Journal of Agricultural Food Chemistry, 2. 244–251.

Bell, R.W., Rerkasem, B., Keerati-Kasikorn, P., Phetchawee, S., Hiranburana, N., Ratanarat, S., Pongsakul, P. and Loneragan, J.F. 1990. Mineral Nutrition of Food Legumes in Thailand with Particular Reference to Micronutrients. ACIAR Technical Reports No. 16, Canberra, Australian Centre for International Agricultural Research.

Bergmann, W. 1983. Ernahrungsstorungen bei Kulturpflanzen. Entstehung und Diagnose. Jena, VEB Gustav Fischer Verlag. 614 p.

Blackman, F.F. 1905. Optima and limiting factors. Annals of Botany, 14. 281–295.

Bouma, D. 1983. Diagnosis of mineral deficiencies using plant tests. In: Lauchli, A. and Bieleski, R.L., ed., Inorganic Plant Nutrition. Encyclopedia of Plant Nutrition NS 15A. Berlin, Springer-Verlag. 120–146.

Bowen, J.E. 1990. Plant tissue analysis of sugarcane. In: Westerman, R.L. ed., Soil Testing and Plant Analysis. 3rd edn. Madison, Soil Science Society of America. 449–467.

Bussler, W. 1981. Physiological functions and utilization of copper. In: Loneragan, J.F., Robson, A.D. and Graham, R.D., ed., Copper in Soils and Plants. New York, Academic Press.

Chapman, H.D., ed., 1966. Diagnostic Criteria for Plants and Soils. Riverside, Division of Agricultural Science, University of California. 793p.

Chen, Y. and Barak, P. 1982. Iron nutrition of plants in calcareous soils. Advances in Agronomy, 35. 217–240.

Delhaize, E., Loneragan, J.F. and Webb, J. 1982. Enzymatic diagnosis of copper deficiency in subterranean clover. II. A simple field test. Australian Journal of Agricultural Research, 33. 981–987.

Dahnke, W.C. and Johnson, G.V. 1990. Testing soils for available nitrogen. In: Westerman, R.L., ed., Soil Testing and Plant Analysis. 3rd edn. Madison, Soil Science Society of America Inc., 127–139.

Elliott, D.E., Pelham, S.D. and Reuter, D.J. 1993. Synchronising diagnosis and correction of nitrogen deficiency in barley grown in semi-arid environments. In: Barrow, N.J., ed., Plant Nutrition — from genetic engineering to field practice. Dordrecht, Kluwer Academic. 475–478.

Graham, R.D. 1984. Breeding for nutritional characteristics in cereals. In: Tinker, P.B. and Lauchili, A., ed., Advances in Plant Nutrition. New York, Praeger. 57–102.

Grundon, N.J., Edwards, D.G., Takkar, P.N., Asher, C.J. and Clark, R.B. 1987. Nutritional Disorders of Grain Sorghum, ACIAR Monograph No. 2, Canberra, Australian Centre for International Agricultural Research, 99 p.

Handson, P.D. and Shelley, B.C. 1993. A review of plant analysis in Australia. Australian Journal of Experimental Agriculture, 33, 1029–1038.

Hannam, R.J., Graham, R.D. and Riggs, J.L. 1985. Diagnosis and prognosis of manganese deficiency in *Lupinus angustifolius*. Australian Journal of Agricultural Research. 36, 765–777.

Hill, J., Robson, A.D. and Loneragan, J.F. 1978. The effects of copper and nitrogen supply on the retranslocation of copper in four cultivars of wheat. Australian Journal of Agricultural Research. 29, 925–939.

Jones, J.B.Jr. 1993. Modern interpretation systems for soil and plant analysis in the United States of America. Australian Journal of Experimental Agriculture, 33. 1039–1043.

Jongruaysup, S., Bell, R.W. and Dell, B. 1994. Diagnosis and prognosis of molybdenum deficiency in black gram (*Vigna mungo* L. Hepper) by plant analysis. Australian Journal of Agricultural Research, 45. 195–201.

Katyal, J.C. and Ponnamperuma, F.N. 1974. Zinc deficiency. A widespread nutritional disorder of rice in Agusan del Norte. Journal of Philippines Agriculture, 58(3,4). 7–9.

Kerridge, P.C., Cook, B.G. and Everett, M.L. 1973. Application of molybdenum trioxide in the seed pellet for subtropical pasture legumes. Tropical Grasslands, 7. 229–232.

Kirk, G.J. and Loneragan, J.F. 1988. Functional boron requirement for leaf expansion and its use as a critical value for diagnosis of boron deficiency in soybean. Agronomy Journal, 80. 758–762.

Loneragan, J.F. 1968. Nutrient requirement of plants. Nature, London, 220. 1307–1308.

— 1970. The contribution of research in plant nutrition to the development of Australian pastures. Proceedings of the XI International Grasslands Congress, Surfers Paradise, Queensland, A13–A32.

— 1978. Anomalies in the relationship of nutrient concentrations to plant yield. In: Plant Nutrition. Ferguson, A.R., Bieliski, R.L. and Ferguson, I.B., ed.: Proceedings of 8th International Colloquium on Plant Analysis and Fertilizer Problems, Auckland, New Zealand 1978. Wellington, New Zealand Department of Scientific and Industrial Research Information Series No. 134, 1. 283–298.

Loneragan, J.F., Snowball, K. and Robson, A.D. 1976. Remobilization of nutrients and its significance in plant nutrition. In: Wardlaw, I.F. and Passioura, J.B. ed. Transport and Transfer Processes in Plants. London, Academic Press. 463–469.

McLaughlin, M.J., Lancaster, P.A., Sale, P.W.G., Uren, N.C. and Peverill, K.I. 1993. Use of cation/anion exchange membranes for multi-element testing of acidic soils. In: Barrow, N.J., ed., Plant Nutrition — from genetic engineering to field practice. Dordrecht, Kluwer Academic. 249–252.

Meagher, W.R., Johnson, C.M. and Stout, P.R. 1952. Molybdenum requirement of leguminous plants supplied with fixed nitrogen. Plant Physiology, Lancaster, 27. 223–230.

Nable, R.O., Bar-Akiva, A. and Loneragan, J.F. 1984. Functional manganese requirement and its use as a critical value for diagnosis of manganese deficiency in subterranean clover (*Trifolium subterranean* L. cv. Seaton Park. Annals of Botany, 54. 39–49.

Netsangtip, R., Rerkasem, B., Bell, R.W. and Loneragan, J.F. 1985. A field survey of boron deficiency in peanut grown in Chiang Mai Valley. Thai Agricultural Research Journal, 3. 171–17. (in Thai)

Randall, P.J. 1969. Changes in nitrate reductase levels on restoration of molybdenum to moybdenum-deficient plants. Australian Journal of Agricultural Research, 20. 633–642.

Rao, N.R. and Ownby, J.D. 1993. Development of an ELIZA for estimation of the copper nutritional status of wheat and cotton. In: Barrow, N.J., ed., Plant Nutrition — from genetic engineering to field practice. Dordrecht, Kluwer Academic. 609–672.

Rerkasem, B., Bell, R.W. and Loneragan, J.F. 1990. Effects of seed and soil boron on early seedling growth of black and green gram (*Vinga mungo* and *V. radiata*). In: Van Beusichem, M.L., ed., Plant Nutrition — physiology and applications. Dordrecht, Kluwer Academic. 281–285.

Reuter, D.J. and Robinson, J.B 1986. Plant Analysis: An Interpretation Manual. Melbourne, Inkata Press, 218 p.

Reuter, D.J., Robinson, J.B., Peverill, K.I. and Price, G.H. 1993. Guidelines for collecting, handling and analysing plant material. In: Plant Analysis: an interpretation manual. Melbourne, Inkata Press. 20–33.

Reuter, D.J., Robson, A.D., Loneragan, J.F. and Tranthim-Fryer. 1981 a. Copper nutrition of subterranean clover (*Trifolium subterraneum* L. cv. Seaton Park). I. Effects of copper supply on growth and development. Australian Journal of Agricultural Research, 32. 257–266.

— 1981 b. Copper nutrition of subterranean clover (*Trifolium subterranean* L. cv. Seaton Park). II. Effect of copper supply on the distribution of copper and deficiency diagnosis by plant analysis. Australian Journal of Agricultural Research, 32. 267–282.

Reuter, D.J., Robson, A.D., Loneragan, J.F. and Plaskett, D. 1982. Zinc in subterranean clover (*Trifolium subterranean* L. cv. Seaton Park). I. Effects of zinc supply on distribution of zinc and dry weight among plant parts. Australian Journal of Agricultural Research, 33. 989–999.

Robinson, J.B. 1993. Fruit, vines and nuts. In: Plant Analysis: an interpretation manual. Melbourne, Inkata Press. 120–147.

Robson, A.D. and Mead, G.R. 1980. Seed cobalt in *Lupinus angustifolius*. Australian Journal of Agricultural Research, 31. 109–116.

Robson, A.D., Nualsri, L. and Loneragan, J.F. 1977. Diagnosis of copper deficiency in peanuts by plant tissue analysis. Proceedings of Conference on Classification and Management of Tropical Soils. International Society of Soil Science, Commissions IV and V, August 1977, Kuala Lumpur. 324–333.

Scaife, A. and Turner, M.K. 1987. Field measurements of sap and soil nitrate to predict nitrogen top-dressing requirements of brussels sprouts. Journal of Plant Nutrition, 10. 1705–1712.

Smith, F.W. 1986. Interpretation of plant analysis. In: Reuter, D.J. and Robinson, J.B ed., Plant Analysis: An Interpretation Manual. Melbourne, Inkata Press, 1–12.

Snowball, K. and Robson, A.D. 1986. Symptoms of Nutrient Deficiencies: Lupins, Perth, University of Western Australia, 81 p.

Spear, S.N., Edwards, D.G. and Asher, C.J. 1978. Response of cassava (*Manihot esculenta* Cranz) to potassium concentrations in solution: critical potassium concentrations in plants grown with a constant or variable potassium supply. Field Crops Research, 2. 153–168.

Ulrich, A. and Hills, F.J. 1967. Principles and practice of plant analysis. In: Soil Testing and Plant Analysis. Part II. Soil Science Society of America, Special Publications Series 2. Madison, Soil Science Society of America Inc. 11–24.

— 1990. Plant analysis as an aid in fertilising sugar beet. In: Westerman, R.L., ed., Soil Testing and Plant Analysis. 3rd edn. Madison, Soil Science Society of America Inc. 429–447.

Walworth, J.L. and Sumner, M.E. 1987. The diagnosis and recommendation integrated system. In: Stewart, B.A., ed., Advances in Soil Science. New York, Springer-Verlag. 149–188.

Waring, E.J., Wilson, R.D. and Shirlow, N.S. 1948. 'Whip-tail' of cauliflower: control by the use of ammonium molybdate and sodium molybdate. Agricultural Gazette of New South Wales, 59. 625–630.

Westerman, R.L. 1990. Soil Testing and Plant Analysis. 3rd edn. Madison, Soil Science Society of America Inc., 784 p.

Williams, C.M.J. and Maier, N.A. 1990. Journal of Plant Nutrition, 13. 985–993.

Root Crops in the Pacific Region: Their Dietary, Cultural and Economic Significance

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Abstract

The major root and tuber crops of the tropics are the edible aroids, cassava, sweet potato and yam. These crops have evolved a special role as the major staple and source of dietary energy in the Pacific Island countries. More recently, importation of other staples such as rice and wheat in some places has made inroads into the root crop economy, diminishing the perceived need for research on improvements in the culture and production of root crops.

This paper reviews recent progress on different aspects of the use, cultivation and economics of root crops in the Pacific region. Cultural preferences for different root crops and methods for their preparation and cooking vary considerably across the region. Research suggests that the nutritional value of sweet potato and other root crops can be improved by selection and breeding. Statistics from the Pacific region show that sweet potato ranked first in production and area harvested in 1993, followed by taro, yam and cassava. Overall production of all root crops increased significantly over the past 30 years, although in some countries production of certain crops has suffered setbacks in particular years. Constraints include not only pests and diseases and the availability of land and water, but also market constraints, labour supply, lack of adequate capitalisation and post-harvest problems.

Considerable potential exists to increase production and use of root crops through the development and adoption of improved production technologies and systems, and improved post-harvest handling and small-scale processing. These advances are necessary to increase the availability to and use of root crops by those who rely on them as a major source of energy and nutrition.

TROPICAL root and tuber crops have long been cultivated in tropical areas of the Pacific, Asia and Africa and used as the major staple food and source of dietary energy, especially in Pacific island countries (Massal 1956; Plowman 1969; de la Peña 1970; Thaman 1988). Worldwide, the roots and tubers are also important as sources of industrial starch and animal feed. This group of crops includes the edible aroids, cassava, sweet potato and yam. In spite of their importance to the diet and the economy of many island nations, improvement and advances in their production technology have not kept up with market and demands. In some places the importation of other staple foods, particularly rice and wheat, has begun to diminish the need for research and improvement in the culture and production of root crops (Thaman 1988).

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Nutrition Values

Much work has gone into the assessment of the nutrition value of the various root crops (Bradbury and Holloway 1988; Wenkam 1983, 1986; Standal 1983; Onwueme 1978; Thaman 1988; Thirumaran et al. 1988; Huang 1982; Parkinson 1984; Splittstoesser 1977; Purcell et al. 1972). Analyses of the nutritional value of the different root crops from various sources are shown in Tables 1, 2 and 3. While cereals provide much of the dietary energy for a large segment of the global population, root crops are a preferred source of energy in a majority of the island nations of the Pacific. Even in Hawaii, in the early days, taro and sweet potato were the major sources of starch and carbohydrates in the diet of the Hawaiian people (Handy 1940; Plucknett and de la Peña 1971).

Although the root crops are chiefly regarded as energy foods, they could also serve to maintain protein balance for a large portion of the population.

Table 1. Nutrient content of tropical root crops compared with rice (data on a fresh weight basis).

Composition	Sweet potato tuber	Cassava tuber	Yam, *D. Esculenta* tuber	Taro, *Colocasia* corm	Rice polished
Moisture (%)	71	63	74	69	12
Energy (kJ/100 g)	460	610	414	490	1500
Protein (%)	1.4	0.5	2.0	1.1	6.5
Dietary Fibre (%)	1.6	1.5	1.2	1.5	2.4
Minerals (mg/100 g)					
Ca	29	20	8	32	4
Fe	0.4	0.2	0.8	0.5	0.5
Vitamins (mg/100 g)					
Vitamin A	0.01	trace	0.02	0.01	0
Thiamin	0.09	0.05	0.05	0.03	0.08
Riboflavin	0.03	0.05	0.03	0.03	0.03
Nicotinic Acid	0.6	0.6	0.4	0.8	3.0
Vitamin C	24	15	20	15	0

Source: Bradbury and Holloway 1988.

Table 2. Nutritional value of some starch foods of the Pacific (per 100 g fresh weight).

Food	Energy kJ	Protein g	Fat g	Carbohydrate g	Ca mg	Fe mg	Vit A g	Thiamin mg	Riboflavin mg	Niacin mg	Vit. C mg
Breadfruit, pulp	470	1.5	0.4	26	25	1.0	trace	0.10	0.06	1.2	20
Cassava, fresh	640	0.7	0.2	37	25	1.0	trace	0.07	0.03	0.7	30
Cassava, flour	1430	1.5	trace	84	55	2.0	trace	0.04	0.04	0.8	0
Plantain	540	1.0	0.2	31	7	0.5	30	0.05	0.05	0.7	20
Potato	310	2.0	trace	17	10	0.7	trace	0.10	0.03	1.5	15
Sweet potato	480	1.5	0.3	26	25	1.0	30	0.10	0.04	0.7	30
Taro	470	2.0	trace	26	25	1.0	trace	0.10	0.03	1.0	5
Yam, fresh	440	2.0	0.2	24	10	1.2	6	0.10	0.03	0.4	10
Yam, flour	1330	3.5	0.3	75	20	10.0	trace	0.15	0.10	1.0	0

Source: Pollock, 1992.

Table 3. Nutrient analyses of taro, sweet potato and cassava leaves (per 100 g fresh weight).

Composition	Taro[a]	Taro[b]	Sweet potato[c]	Sweet potato[b]	Cassava[d]
Moisture (g)	79.6	87.54	86.1	87.8	80
Protein (g)	4.4	4.98	2.74	4	6.0
Fat (g)	1.8	0.74		0.3	1.0
Carbohydrate (g)	12.2	4.82		6.6	7.0
Fibre (g)	3.4	2.02	1.96	1.2	
Energy (kcal)	69	36		36	50
Minerals					
Ca (mg)	268	107	74.4	37	200
P (mg)	78	60		94	
Fe (mg)	4.3	2.25	3.94	1.02	300
K (mg)	1237	437		525	
Vitamins					
Carotene IU[1]	20385	5028	5580	1787	
Thiamin (mg)	0.10	0.14		.16	.20
Riboflavin (mg)	0.33	0.31	0.35	.37	.30
Niacin (mg)	2.0	1.0		1.14	1.50
Vitamin C (mg)	142	37	4.1	11.0	200

Sources:
a — Tisbe and Cadiz 1967. b — Wenkam 1983. c — Luh and Moomaw 1982. d — Onwueme 1978.
[1] International Units.

Estimates of the protein content of root crops have shown that much variation occurs among varieties within each root crop species. For example, Splittstoesser (1977) showed that protein content of cassava roots ranges from 1.2 to 2.7%, potato 1.2 to 19.1% with an average of 5%, sweet potato 1.7 to 11.8%, yams 6.6 to 13.4%, and taro corms 1.0 to 4.5% on a dry weight basis.

Purcell et al. (1972) suggested that protein content of sweet potato and perhaps other root crops can be improved through selection and breeding since such a wide range of protein content exists in the tropical root crops. A less explored source of nutritious food is the young leaves of taro and the young shoot of sweet potato. In many island nations in the Pacific, young taro leaves are prized as vegetables because of their high nutrient content. In Samoa, young taro leaves are cooked and called 'palusami'; in Hawaii they are called 'luau leaves' and cooked with meat or fish in an underground oven called 'imu'. Undoubtedly, other island nations have their own names and ways of cooking taro and sweet potato leaves. Many Asian countries also use sweet potato leaves for cooking. Nutrient analyses (Table 3) show that they are highly nutritious (Miller and Branthoover 1957; Luh and Moomaw 1982; Taylor 1982; Wenkam 1986). Even young cassava shoots find their way into the kitchen as they are also edible when properly cooked (Onwueme 1978; Evensen and Standal 1984).

In spite of the popularity of the root crops among Pacific Island countries, the use of imported and foreign food sources, especially cereals, is increasing. The rising popularity of cereals is due to several factors. They are more convenient, store well, can be cooked with less time and fuel, and invariably are cheaper. Root crops in general have a shorter shelf-life and are harder to store in natural form. Because they are utilised in fresh form, they take longer to prepare and cook.

In Samoa taro is preferred to other crops and in Tonga, yams, followed by taro, are still popular. *Alocasia* serves as an important reserve food while many atoll people grow *Cyrtosperma* for their source of carbohydrate. Sweet potato has become a major food crop in Solomon Islands and in Papua New Guinea (Bourke 1982).

Apart from their traditional or daily food uses, many root crops, especially yam and taro, remain as preferred feast and ceremonial foods in Fiji, Tonga and Samoa (Parkinson 1984).

Production

Individual country statistics are often not readily available (Bourke 1982; Sivan and Liyanage 1992). However, FAO (1972–1993) has compiled yearly statistics on the production, area and yield of world major crops, which include the root and tuber crops.

Tables 4 and 5 show the world's harvested area and production of the major root crops from 1962 to 1993. It can be seen from Table 4 that total area of all root crops harvested has been almost constant, showing very little fluctuation from 1962 to 1993. The peak in harvested area occurred in 1974 when approximately 56.5 million ha were used. Potato and sweet potato both decreased steadily in area harvested resulting in a 20% and 27% decline, respectively. Cassava, yam and taro, on the other hand, increased in area from 1962 to 1993. Cassava showed the biggest increase at 88% while yam and taro increased 61% and 54%, respectively (Table 4).

During the same period (1962–93), the world's total root crop production increased by 30% (Table 5). In the countries of Oceania some crops increased while others decreased in both area harvested and production. Changes in harvested area throughout Oceania were: total root crops, +78%; potato, –2%; sweet potato, +606%; cassava, –73%; yam, +200%; taro, +194% (Table 6).

Table 4. World root and tuber crops production (area harvested in '000 ha).

Year	Total[1]	Potato	S. Potato	Cassava	Yam	Taro
1962	47 710	23 805	12 473	8 501	1 819	636
1967	50 233	23 033	13 908	10 131	1 928	669
1972	51 376	21 981	14 875	11 196	1 946	742
1977	51 898	20 945	14 334	12 575		
1982	47 883	17 673	11 104	14 513	2 523	1 124
1987	46 402	18 177	9 292	14 397	2 566	988
1993	48 126	19 133	9 111	16 002	2 933	978
Change*	+0.9%	–20%	–27%	+88%	+61%	+54%

Source: FAO Production Yearbook, 1973–1993, Vol. 27–47.
* Percent change in area from 1962 to 1993.
[1] Total includes not specified minor root crops.

Table 5. World root and tuber crops production ('000 t).

Year	Total[1]	Potato	S. Potato	Cassava	Yam	Taro
1962	462 591	264 777	103 536	72 550	16 266	3 317
1967	534 254	308 223	116 341	88 297	15 150	3 656
1972	533 924	281 409	124 382	102 618	18 457	4 088
1977	570 211	292 938	138 148	110 167		
1982	556 362	254 861	140 186	128 944		
1987	593 948	285 009	135 236	137 291	26 968	5 737
1993	603 195	288 183	123 750	153 628	28 126	5 639
Change*	+30%	+9%	+19.5%	+112%	+73%	+70%

Source: FAO Production Yearbook, 1973–1993, Vol. 27–47.
* Percent change in production from 1962 to 1993.
[1] Total includes not specified minor root crops.

Table 6. Root crop production in Oceania.

Crops	Area harvested ('000 ha)			Production ('000 t)		
	1962	1993	Change	1962	1993	Change
Total*	156	277	+78%	1 587	3 137	+98%
Potato	50	49	−2%	777	1 392	+79%
Sweet potato	17	120	+606%	170	585	+244%
Cassava	62	17	−73%	449	208	−54%
Yam	6	18	+200%	60	290	+383%
Taro	16	47	+194%	78	333	+327%

Source: FAO Production Yearbook, 1973–1993, Vol. 27–47.
* Total root crops include minor and non-specified root crops.

During the same period world potato production increased by 9%, sweet potato by 20%, cassava by 112%, yam by 73% and taro by 70% (Table 5). In the Oceania region, only the total production of cassava decreased 54% while all other root crops increased (total root crops, 98%; potato, 79%; sweet potato, 244%; yam, 383%; and taro, 327%) (Table 6). The decrease in production of cassava contradicts reports that its use in many Pacific Island countries is increasing at the expense of the other root crops, particularly yam and taro (Parkinson 1984).

The last three years of data, 1991–93, show the following trends for Oceania and the world (Tables 7, 8, and 9).

(1) The average yields of all root crops of the world in 1991, 1992 and 1993 were 12 180 kg/ha, 12 249 kg/ha and 12 534 kg/ha, respectively.

(2) In sweet potato production, China ranks first in area and total production at 6.2 million ha and 105.2 million t in 1993. In the Pacific, Papua New Guinea is the highest producer of sweet potato, using 106 000 ha with a production of 480 000 t. Tonga (7000 ha and 14 000 t) and Solomon Islands (4000 ha and 52 000 t) follow. The Cook Islands among the Pacific Island nations had the highest yield at 27 500 kg/ha; however, total sweet potato production was only about 2000 t.

(3) Among the tropical root crops, cassava is first in area and total production in the world. In 1993, total production was approximately 153.6 million t from 16 million ha. Sweet potato ranked second with a production of 123.8 million t from 9.1 million ha. Yam production was 28 million t from 2.9 million ha and taro production was 5.6 million t from 978 000 ha. Among the Pacific Island nations, Papua New Guinea produced most cassava with a production in 1993 of 113 000 t from 11 000 ha. Fiji produced 40 000 t from 2000 ha and Tonga 28 000 t from 2000 ha.

(4) In the Pacific, sweet potato ranked first in production and area harvested in 1993, followed by taro, yam and cassava.

(5) Africa led the rest of the world in yam production in 1993 with 26.8 million t or 95% of

total world production. Nigeria (20 million t) and Ivory Coast (2.5 million t) were the top yam-producing countries. Papua New Guinea produced 220 000 t from 13 000 ha followed by Tonga and Solomon Islands producing 31 000 t and 20 000 t, respectively.

(6) Among the tropical root crops worldwide, taro ranks last in total production and area harvested. Again, Africa leads in production with a total of 3.5 million t representing 61% of the world's taro production. In 1993, Papua New Guinea produced 218 000 t from an area of 33 000 ha. Other Pacific countries with significant taro production were Samoa (37 000 t, 6000 ha), Tonga (27 000 t, 4000 ha), Solomon Islands (26 000 t, 1000 ha), and Fiji (15 000 t, 1000 ha).

(7) Taro yields worldwide are the lowest amongst the tropical root crops at 5.6 t/ha. This suggests a need for considerable research and development to improve production technology.

Table 7. Total root crops area harvested ('000 ha) 1991–93.

Crops	1991		1992		1993	
	Oceania	World	Oceania	World	Oceania	World
Total	291	46 174	256	46 846	251	47 157
Potato	91	17 710	55	18 031	49	18 133
S. Potato	118	9 260	119	9 262	120	9 111
Cassava	17	15 671	17	15 757	17	16 002
Yam	18	2 546	18	2 803	18	2 933
Taro	47	987	47	993	47	978

Source: FAO Production Yearbook, 1991–1993, Vol. 45–47.

Table 8. Average root crop yields 1991–93 (kg/ha).

Crops	1991		1992		1993	
	Oceania	World	Oceania	World	Oceania	World
Total	11 639	12 180	11 300	12 249	11 339	12 534
Potato	29 844	14 746	26 092	14 890	28 129	15 892
S. Potato	4 841	13 628	4 876	13 821	4 879	13 582
Cassava	11 060	9 808	11 127	9 660	12 056	9 601
Yam	16 123	9 385	16 130	9 923	16 028	9 589
Taro	7 139	5 799	7 178	5 649	7 035	5 767

Source: FAO Production Yearbook, 1991–1993, Vol. 45–47.

Table 9. Total root crop production 1991–93 ('000/t).

Crops	1991		1992		1993	
	Oceania	World	Oceania	World	Oceania	World
Total	2 851	570 655	2 842	582 147	2 808	599 326
Potato	1 467	261 162	1 440	268 492	1 392	288 183
S. Potato	570	126 187	578	128 016	585	123 750
Cassava	191	153 689	194	152 218	208	153 628
Yam	288	23 893	293	27 814	290	28 126
Taro	335	5 724	337	5 607	333	5 639

Source: FAO Production Yearbook, 1991–1993, Vol. 45–47.

Production Constraints

Major production constraints in many Pacific Island countries as well as in other root crop producing countries include the following.

Availability of land and water — many of the Pacific Island countries, particularly the atolls, have very limited land area. This precludes large-scale production of any crop. Even in such larger countries as Fiji and Papua New Guinea, root crop production is usually limited to small-scale farmers restricted to rugged topography, because relatively level areas are reserved for the urban population and for production of more lucrative crops. In almost all the root crop producing areas, planting is usually timed to coincide with the onset of the rainy season because during the drier months sources of water for irrigation are limited.

Labor supply — root crop production requires a high input of labor. Most farming operations to grow root crops require manual labour. Land preparation, especially in small and hilly areas, cannot be mechanised. Preparation of planting material also requires a tremendous amount of labour since all the root crops are commercially propagated using vegetative materials (tubers, vines and cuttings). Various workers have estimated that root crop production requires approximately 600–2000 labour hours/ha.

In Hawaii, agricultural economists estimated that the labour cost of producing taro ranges from 50 to 70% of the estimated gross return even with the use of farm machinery (Begley et al. 1980; Vieth et al. 1980). Likewise, the average estimated labour cost of producing sweet potato is 40% of expected revenue (Huang and Marutani 1979).

Lack of adequate capital — the traditional farming systems in many of the island countries are limited to small areas where the product is usually consumed by the family. Small surpluses are sold in the open market. Even when capital is available from national development and commercial banks for large-scale production, growers would need a guaranteed market to be able to obtain the necessary credit.

Market constraints — most of the root crop produced is consumed on-farm and/or in the general area where grown. Any root crops sold are usually surplus and ungraded. With a few exceptions (Fiji, Samoa, Cook Islands) very little root crop is intended for export and/or processing. Cassava in Thailand and Indonesia is grown for the cassava flour market and is therefore brought to the processing plants or prepared by chipping and drying for the processors. Most local markets in the Pacific Island countries are small, and any unforeseen or sudden increases in production can easily disturb the balance of supply and demand and cause sharp changes in market prices. In Hawaii, two major products made from taro are poi and taro chips. Both poi and taro chips are relatively expensive due to the declining production of taro. A sudden increase in taro production could cause a drastic cut in the farmers' price for fresh taro corms. Likewise, any sudden change in the amounts of root crops sold in individual countries can cause a significant and sudden fluctuation in price.

Lack of improved production techniques — because root crops are traditionally grown as subsistence crops, not for large markets, the farming technology used is old-fashioned. Unlike export crop production, very little, if any, fertilizer is used in root crop production. Even when fertilizer experiments clearly show marked increases in production, farmers do not follow recommendations made by extension workers and researchers. For example, experiments in Fiji, Samoa, Hawaii, Tonga, Solomon Islands, Papua New Guinea and Cook Islands show that with modest applications of N, P, and K fertilizers, yields of sweet potato, taro, yam and cassava can be increased three to four times (de la Peña 1967; Anders 1975; Bourke 1982; Cable and Asghar 1984; Moles et al. 1984).

Effective weed control is critical in the production of root crops. Lack of cost-effective methods of controlling weeds, whether manual or chemical, is a deterrent to good root crop production. Proper use of cheap, locally available mulching materials such as coconut leaves, banana leaves and dried grass can all be effective in weed control and hence the production of root crops. Mulching not only suppresses weeds but also helps to conserve moisture critical for the growth of all plants. The use of natural mulches in the Cook Islands, Samoa and elsewhere illustrates the value of mulching (Lambert 1982).

Planting root crops using optimum spacing allows for efficient use of scarce land. Proper spacing also prevents excessive competition from weeds which can overgrow when the main crops are spaced too far apart (de la Peña 1978).

The use of improved, high-yielding cultivars with some tolerance or resistance to the many pests and diseases of the region will go a long way toward improving root crop production. Although some variety improvement through selection and breeding is now in progress in Solomon Islands, Fiji, Samoa and Hawaii, progress is slow and the process expensive. Evaluation of existing cultivars in each of the root crop producing countries is also minimal and farmers are forced to use primitive varieties which are generally low-yielding. In addition to improved cultivars, there is urgent need for sources of clean, disease-free planting materials.

Diseases and pests — there is in the Pacific region a high incidence of diseases and pests of root crops which often cause severe crop failures (O'Connor 1969). A classic example is the recent epidemic of taro leaf blight in American and Western Samoa. All the root crops are attacked by a number of insects and other pests. All are also susceptible to several bacterial, fungal and virus diseases.

Inadequate post-harvest handling and processing — under small-scale subsistence farming conditions, root crops are harvested and used almost immediately. In this situation, post-harvest treatments and handling are not important. Root crops can be field-stored, which involves no form of expensive treatment or processing. However, when root crops are brought to the market, cleaning and adequate post-harvest treatment to assure a good-quality marketable product is needed. Often, on small farms, farmers do not practise good post-harvest cleaning and preparation for the market, so that the products being sold have a very short shelf-life.

Cassava and taro are notoriously sensitive once harvested because, unlike yams and sweet potato, they start to deteriorate immediately after harvest. Yams and sweet potato can be cured and stored for considerably longer periods. Some research has been done to increase the storability of both cassava and taro especially for the export market; however, their shelf-life is still relatively short compared to yam and sweet potato (Coursey et al. 1979).

Potential for Root Crop Development and Expansion

World statistics show that there has been a steady increase in total production of the tropical root crops from 1962 to 1993, although this increase did not keep up with population growth (Table 5). Despite some reports that root crop production and utilisation in the Pacific region are in decline, production of sweet potato, cassava, yam and taro in the region from 1991 to 1993 has been steady. These crops should continue to play an important role in the nutrition of the people of the Pacific area, and will also continue to play an important role in providing energy and nutrition to the world's population, which is increasing at a rate faster than farmers can increase food production capability.

Research into and development of other uses of root crops, such as poi for baby food and food for people allergic to cereals and other staples, will lead to increased root crop production. Their use as a wheat flour substitute in the baking industry will also increase their value to the producing countries.

To help increase the levels of their production and utilisation in the Pacific, several factors need to be taken into consideration.

Improved production technology — farmers should have access to results of research on proper fertilisation, weed control, plant spacing, control of pests and diseases, irrigation, etc. Improved cultivars resistant to the major insects, pests and diseases of the region could dramatically increase yields without the application of expensive control measures.

Improved post-harvest handling and small-scale processing — root crops, especially cassava and taro, need special post-harvest handling to maintain quality and improve marketability and shelf-life. Increased farmer awareness of the vulnerability of the crops to rapid spoilage and improved techniques of harvesting to minimise bruising can help extend storage and shelf-life.

Low-technology processing techniques should be introduced to minimise spoilage and increase storability. Thailand and Indonesia are already processing cassava into flour on a commercial scale (Falcon et al. 1984; Titapiwatanakun 1990). Other countries can establish small processing plants to accommodate other root crops like taro and sweet potato. In flour form, these products can be stored indefinitely. They can also be used for other food preparation including their use as a substitute for wheat flour (Tu et al. 1979; Pedrana 1979). Canning or bottling root crops can be accomplished with minimal use of equipment and capital. Chipping and solar drying can be a very inexpensive technique for increasing their shelf-life and storage (Lambert 1982; Chandra 1979; Siki 1979; Moy and Nip 1980).

Improved packaging not only prevents rapid deterioration of the root crops but also increases their acceptance by consumers.

Improved production system — many root crop producing countries have very limited land area. A more efficient and improved management and production system can help increase production without increasing the area used for cultivation (Wang and Steinke 1983). For example, farmers in Hawaii plant taro throughout the year. Taro for poi and chips is harvested every week.

To provide a constant and weekly supply of taro for processing, farmers have to maintain sufficient plantings. By following a rigid schedule of planting, a farmer can harvest sufficient taro to fill a weekly 'quota'. The quota or number of 38-kg bags a farmer harvests every week depends on the size of the farm and his ability to maintain a constant supply for the processor.

Since Hawaiian taro farmers do not harvest more than the required shipment for a week, special packaging and storage is not needed and processors are also able to keep a constant supply of fresh poi in the market.

The taro chip market is similar, except that taro chips have the added advantage of longer shelf-life than poi. An improvement in the production and management of these crops will also increase their availability for the consumption and use of those who rely on them as a major source of energy and nutrition on a regular basis.

References

Anders, M. M. 1975. Root crop research in the Kingdom of Tonga. Regional Meeting on the Production of Root Crops, 24–29 October 1975, Suva, Fiji. South Pacific Commission Technical Paper No. 174. 200–202.

Begley, B. W., Vieth, G. R. and de la Peña, R. S. 1980. Commercial dryland taro in Hawaii: estimates of the costs of production on small and medium sized farms. Department of Agricultural Economics. University of Hawaii, USA.

Bourke, R. M. 1982. Sweet potato in Papua New Guinea. In: Villareal, R. L. and Griegs, T. D. ed. Sweet Potato. Proceedings of the First International Symposium. AVRDC Publication No. 82–172. 45–58.

Bradbury, J. H. and Holloway, W. D. 1988. Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific. ACIAR Monograph No. 6. 201 p.

Cable, W. J. and Asghar, M. 1984. Some recent research on edible aroids in Western Samoa. In: Chandra, S. ed. Edible Aroids. Clarendon Press, Oxford. 80–87.

Chandra, S. 1979. Handling, storage and processing of root crops in Fiji. In: Plucknett, D. L. ed. Small-Scale Processing and Storage of Tropical Root Crops. Westview Tropical Agri. Series No. 1. Boulder, Colorado. Westview Press. 53–63.

Coursey, D. G., Jackson, G. V. H. and de la Peña, R. S. 1979. Working Group Report: Handling and Storage. In: Plucknett, D. L. ed. Small-scale Processing and Storage of Tropical Root Crops. Westview Tropical Agriculture Series No. 1. Boulder, Colorado. Westview Press. 15–25.

de la Peña, R. S. 1967. Effects of different levels of N, P, and K fertilisation on the growth and yield of upland and lowland taro (*Colocasia esculenta* [L.] Schott, var. Lehua). PhD dissertation, University of Hawaii, USA.

— 1970. The edible aroids in the Asian-Pacific area. Proceedings 2nd International Symposium on Tropical Root and Tuber Crops (1970), Vol. 1. 136–140.

— 1978. Yields of upland and lowland taro at varying plant densities. Field Crops Research 1. 183–190.

Evensen, S. K. and Standal, B. R. 1984. Use of tropical vegetables to improve diets in the Pacific region. Hawaii Institute of Tropical Agriculture and Human Resources, Research Series 028. 32 p.

FAO, 1972–1993. Production Yearbooks. Food and Agriculture Organization of the United Nations, Rome, Vols. 27–47.

Falcon, W. P., Jones, W. O., Pearson, S. R. et al. 1984. The Cassava Economy of Java. Stanford University Press.

Handy, E. S. C. 1940. The Hawaiian Planter. I. His plants and areas of cultivation. Bernice P. Bishop Museum Bulletin. p.161.

Huang, P. C. 1982. Nutritive value of sweet potato. In: Villareal, R. L. and Griegs, T. D. ed. Sweet Potato. Proceedings of the First International Symposium. AVRDC Publication No. 82–172. 35–36.

Huang, W. Y. and Marutani, H. K. 1979. Costs and returns of producing sweet potatoes in Hawaii. Hawaii Agricultural Experimental Station Departmental Paper 24. 14 pp.

Lambert, M. ed. 1982. Taro cultivation in the South Pacific. South Pacific Commission Handbook 22.

Luh, C. L. and Moomaw, J. C. 1982. Present and future outlook for sweet potato in Asia research and development needs. Proceedings of the 5th International Symposium on Tropical Root and Tuber Crops, 17–21 Sept. 1979. Los Baños, Laguna, Philippines. 9–26.

Massal, E. 1956. Food plants of the South Sea Islands. SPC Tech. Paper 94. 52 p.

Miller, C. D. and Branthoover, B. 1957. Nutritive values of some Hawaii foods. Hawaii Agricultural Experimental Station Circ. No. 52.

Moles, D. J., Rangai, S. S., Bourke, R. M. and Kasamani, C. T. 1984. Fertilizer response of taro in Papua New Guinea. In: Chandra, S. ed. Edible Aroids. Clarendon Press, Oxford. 64–71.

Moy, J. H. and Nip, W. K. 1980. Processed Food. In: Wang, J. K. ed. Taro: A review of *Colocasia esculenta* and its potentials. University of Hawaii Press. 261–268.

O'Connor, B. A. 1969. Exotic Plant Pests and Diseases. South Pacific Commission.

Onwueme, I. C. 1978. The Tropical Tuber Crops: Yams, Cassava, Sweet Potato, and Cocoyams. John Wiley & Sons.

Parkinson, S. 1984. The contribution of aroids in the nutrition of people in the South Pacific. In: Chandra, S. ed. Edible Aroids. Clarendon Press, Oxford. 215–24.

Pedrana, C. 1979. Processing of root crop products, especially taro and cassava, in Western Samoa. In: Plucknett, D. L. ed. Small-scale Processing and Storage of Tropical Root Crops. Westview Tropical Agriculture Series, No. 1. 258–65.

Plowman, T. 1969. Folk uses of new world aroids. Economic Botany, 23. 97–122.

Plucknett, D. L. and de la Peña, R. S. 1971. Taro production in Hawaii. World Crops 23. 244–49.

Pollock, N. J. 1992. These Roots Remain: Food habits in islands of the Central and Eastern Pacific since Western contact. The Institute for Polynesian Studies. Hawaii, USA.

Purcell, A. E., Swaisgood, H. E. and Pope, D. T. 1972. Protein and amino acid content of sweet potato cultivars. Journal American Society of Horticultural Science, 97. 30–33.

Siki, B. F. 1979. Processing and storage of root crops in Papua New Guinea. In: Plucknett, D. L. ed. Small-Scale Processing and Storage of Tropical Root Crops. Westview Tropical Agriculture Series, No. 1. 64–82.

Sivan, P. and Liyanage, A. de S. 1993. Breeding and evaluation of taro (*Colocasia esculenta*) for the South Pacific Region. Proceedings of the Sustainable Taro Culture for the Pacific Conference, 24–25 Sept. 1992. University of Hawaii, USA. 1–5.

Splittstoesser, W. E. 1977. Protein quality and quantity of tropical roots and tubers. HortScience, 12. 294–98.

Standal, B. R. 1983. Nutritive value. In: Wang, J. K. ed. Taro: A review of *Colocasia esculenta* and its potentials. University of Hawaii Press, USA. 141–47.

Taylor, J. M. 1982. Commercial production of sweet potatoes for flour and feeds. In: Villareal, R. L. and Griggs, T. D. ed. Sweet Potato: Proceedings of the First International Symposium. AVRDC Publication No. 82-172. 393–404.

Thaman, R. R. 1988. Root crops in the nutritional future of the Pacific Islands. Proceedings of the Eighth Symposium of the International Society for Tropical Root Crops. 30 Oct.–5 Nov. 1988. Bangkok, Thailand, 130–46.

Thirumaran, K., Thirumaran, A. S. and Seralathan, M. A. 1988. Studies on the nutritive value and utilization of tubers of *Dioscorea alata* and *Dioscorea esculenta*. Proceedings of the 8th Symposium of the International Society for Tropical Root Crops. 30 Oct.–5 Nov. 1988. Bangkok, Thailand. p. 648.

Tisbe, V. O. and Cadiz, T. G. 1967. Taro or gabi. In: Knott, J. E. and Deanon, J. R., Jr., ed. Vegetable Production in South East Asia. University of the Philippines Press, Los Baños. 293–300.

Titapiwatanakun, B. 1990. Significant factors contributing to the success of the Thai cassava industry. Proceedings 8th Symposium of the International Society for Tropical Root Crops. 30 Oct.–5 Nov. 1988, Bangkok, Thailand, 92–108.

Tu, C. C., Nip, W. K. and Nakayama, T. O. M. 1979. Starch and flour from taro. In: Plucknett, D. L. ed. Small-scale Processing and Storage of Tropical Root Crops. Westview Tropical Agriculture Series, No. 1. 249–57.

Vieth, G. R., Begley, B. W. and Huang, W. Y. 1980. The economics of wetland taro production in Hawaii. Hawaii Agricultural Experimental Station Agricultural Economics Departmental Paper 60.

Wang, J. K. and Steinke, W. E. 1983. Production systems planning. In: Wang, J. K. ed. Taro: A review of *Colocasia esculenta* and its potentials, University of Hawaii Press, USA. 315–45.

Wenkam, N. S. 1983. Foods of Hawaii and the Pacific Basin. Vegetables and vegetable products: Raw, Processed and Prepared. Vol. 1, Hawaiian Institute for Tropical Agriculture and Human Resources. University of Hawaii, USA Research Extension Series 038.

— 1986. Foods of Hawaii and the Pacific Basin. Vegetables and Vegetable Products: Raw, Processed and Prepared. Vol. 2, Haw. Inst. Trop. Agr. and Human Res., University of Hawaii Research Extension Series 065.

Diagnostic Criteria for Nutrition Disorders of Sweet Potato I: Methods and Visible Symptoms

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Abstract

A series of experiments is described in which nutrition disorders of varying intensity were induced in sweet potato (*Ipomoea batatas* cv. Wanmun), using solution culture. The resulting symptoms were described and photographed, and measurements made of the top and root dry weights and the concentration of each nutrient in an index tissue. Subsequently, selected treatments were applied to four cultivars differing in growth habit, leaf shape and colour, in order to assess any differences in expression of visible symptoms. In this paper the methodology is discussed, and the visible symptoms for each disorder described. An accompanying paper describes the results of tissue analyses and the estimation of critical nutrient concentrations.

YIELDS of sweet potato throughout the Pacific region are typically well below the potential yields for the crop. A number of environmental constraints may limit crop productivity, including soil fertility, water supply, temperature, pests and diseases, and weed competition. Poorly nourished plants may be less conspicuous than droughted or diseased crops, and frequently raise no concern amongst farmers or agronomists. However, field surveys throughout the region indicate that nutrition deficiencies are almost universal, placing a great constraint on the productivity of farmers' labour and increasing pressure on land resources. Appropriate measures for correction of nutrition problems depend on accurate diagnosis of the yield-limiting disorder.

Visible symptoms observed in the field can be very informative of a crop's nutrition status. The location of the symptons on the plant help to identify the nutrient responsible. Some nutrients such as nitrogen (N) and potassium (K) may be redistributed readily from older to younger parts of the plant in times of shortage, so symptoms of N and K deficiency are likely to appear first on the oldest leaves. Deficiencies of others like calcium (Ca) and boron (B) are likely to be observed on the younger leaves, as they show very little redistribution. Others, including sulfur (S), are intermediate, and symptoms may be observed on leaves of any age. In some cases, a confident diagnosis can be made on the basis of visible symptoms, particularly if local information on soil characteristics and recent management is known. However, frequently a visual assessment may result in a number of possibilities, which can be resolved only through tissue or soil analysis, or by the response of test plants to the application of each suspect nutrient.

Visible symptoms of some important nutrition disorders in sweet potato have been reported by Bolle-Jones and Ismunadji (1963) and Spence and Ahmad (1967). Clark and Moyer (1988) and Hill (1989) have given summaries of previously reported symptoms for a number of disorders. However, the descriptions were generally not sufficient for diagnosis, and the data on tissue nutrient concentrations were mostly in a form not easily applied to tissue sampled from the field.

The results of an intensive study of nutrition disorders induced in sweet potatoes are reported in this and an accompanying paper. Visible symptoms were recorded in detail, with emphasis on distinguishing

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between similar symptoms induced by separate nutritional disorders, and on differences among cultivars. The descriptions given here are a summary of the most important diagnostic features; more detailed descriptions together with colour illustrations will be published as a subsequent booklet. The results of foliar analyses are reported in the accompanying paper.

Methods

All experiments were performed in a glasshouse in Brisbane during the warmer months of the year (October to May). They cover three growing seasons, from 1992 to 1995. Tip cuttings were taken from field plots, trimmed to two open leaves and 3–5 defoliated nodes, depending on the cultivar, and rooted for approximately 7 days under a mist of deionised water. Individual cuttings were transferred to 22 l pails of aerated nutrient solution, and grown for 28 days. Plants were supported in the lid of the pail using a plastic foam plug, and vines were supported on string extending from the lid to crosswires at about 2.2 m height.

Nutrient supply was based on a modified version of the programmed nutrient addition procedure of Asher and Blamey (1987). Plant growth curves and whole plant nutrient composition were established through preliminary trials, and the NUTRADD computer program was used to convert these data into daily nutrient requirements. Weekly requirements were added at the start of each week. As treatments affected the growth rate of and nutrient consumption by the plants, solutions were monitored weekly using inductively coupled plasma atomic emission spectrometry (ICP–AES) and nutrient additions for each treatment adjusted on the basis of K consumption (or S if K was the test element) so that all treatments contained similar nutrient concentrations after each addition. Nutrient concentrations were relatively low, for example K ranged from approximately 100 μM to 950 μM. Calcium was maintained above 500 μM, and iron (Fe) above 10 μM, except where these were the test elements, in which case the basal dose was reduced by the same factor as the incremental doses. Solution pH was maintained between 5.5 and 6.0 by weekly adjustment. Analytical reagent grade salts and high quality deionised water were used throughout (conductivity less than 0.1 S/m); for micronutrient deficiencies, water was further purified, and macronutrient stock solutions were purified by passage through Chelex 100 chelating resin.

Nutrient deficiencies of varying intensity were induced by supplying various fractions of the calculated demand for the nutrient in question. Toxicities were induced by raising the solution to the treatment concentration over a number of days, after a period of establishment. Typical experiments included four levels of supply below the expected optimum in the deficiency series, and three levels above the optimum in the toxicity series, with four replicates. At harvest, plants were separated into index tissue, tops and roots, and these tissues were dried and weighed. Index tissue was the blades of leaves 7–9, counting from the youngest open leaf on the main stem. In some studies all blades from the main stem of selected plants were sampled in groups of three. Dried samples were analysed by acid digestion and multi-element analysis using ICP–AES, and by Kjeldahl digestion and colorimetric analysis for N and phosphorus (P).

In initial experiments to characterise the growth response to each element, a single cultivar (Wanmun) was chosen on the basis of its widespread use in Papua New Guinea. Further experiments were run to compare symptom development in other cultivars — cvv. Wanmun (origin PNG), Markham (PNG), Lole (Tonga) and Hawaii (Hawaii). In these experiments, only one or two test element levels were applied above or below the estimated optimum, with three replicates. All cultivars were obtained as pathogen-tested plantlets from the Pacific Regional Agricultural Programme (PRAP) Tissue Culture Facility at the University of the South Pacific, Western Samoa. The latter experiments were conducted in the 1994–95 season, and chemical analysis data from them are not yet available.

Results and Discussion

Except for molybdenum (Mo) deficiency, all experiments resulted in visible symptoms and a significant growth reduction attributable to the disorder. The symptoms are summarised below.

Disorders producing symptoms mainly on the older leaves

Nitrogen deficiency

General symptoms are growth reduction and a uniform light green chlorosis of the leaves, symptoms which may be obvious in comparison with healthy plants, but may be difficult to identify in the field (Fig. 1).

Different conditions for the development of N deficiency may lead to different symptoms appearing in the crop. When N is initially adequate during the establishment of the crop but becomes depleted during crop growth, plants may appear normal or near-normal in colour and habit, except for yellowing and premature shedding of older leaves due to remobilisation of N from these tissues. The oldest leaf becomes uniformly yellow and slightly wilted, and is usually shed before it becomes dry or develops extensive necrosis. Senescence is usually rapid and it is normal to find only one yellow leaf at the base of a vine.

Alternatively, if N supply is low throughout the growth of the crop, no senescence of older leaves may be evident. Symptoms of chronic N-deficiency include reduced leaf size, loss of the normal sheen, giving the leaves a dull appearance, thin spindly vines, and reduced activity of axillary shoots leading to less branching.

Increased red pigmentation of the young leaves, and especially the leaf veins, is a noticeable symptom but is not unique to N-deficiency, since P-deficient plants may show a similar symptom. In cultivars in which young leaves are normally pigmented, the purple colour is deepened and is retained for longer in the veins, whereas the leaves of healthy plants change colour uniformly from purple to green. In cultivars which normally display little or no anthocyanin pigment, veins of the young leaves become red or purple.

Phosphorus deficiency

Mild to moderate P deficiency is difficult to recognise in the field. Growth may be reduced to less than one half that in well nourished plants, without the appearance of any identifiable symptoms of stress.

The first sign of P deficiency is usually the premature senescence of older leaves (Fig. 2). In more severe cases, brown necrotic lesions develop in interveinal zones on the older leaves. These are usually preceded by a somewhat larger, diffuse zone of yellow chlorosis, centred between and confined by the main lateral veins, but in some cultivars, the chlorotic stage is missing, and necrotic lesions appear on green tissue. Necrotic zones may spread and coalesce, covering whole sectors of the leaf. Senescence of the oldest leaf proceeds by a fairly rapid yellowing, often spreading from the tip or one side of the leaf. The leaf blade usually becomes entirely brown and dry before dropping.

In most cultivars, a dark purple pigmentation developed on the upper surface of older leaves before the development of necrotic lesions. This was observed particularly but not only in those cultivars which normally have purple-red pigmentation in young leaves. Pigmentation is usually most intense towards the leaf tip. As chlorotic zones develop, these areas become clear of pigment. However, during the general chlorosis associated with leaf senescence, the red pigmentation is retained, and striking autumnal colours may develop in senescing leaves.

Some cultivars may develop purple pigmentation on the upper surface of the youngest leaves, particularly on the veins. This may resemble N-deficiency, although it is less common among cultivars, and is less strongly veinal.

Potassium deficiency

Symptoms of K deficiency become evident on the oldest leaves, which develop a yellow chlorosis in marginal and interveinal zones (Fig. 3). Brown necrotic lesions develop within the chlorotic zones, and may spread to cover the entire leaf blade. Cultivars vary in the extent to which lesions spread predominantly from the margins to interveinal zones, or are initiated in interveinal regions nearer the midrib, or show relatively little regard for veinal distribution. Necrosis associated with K deficiency is usually dark in colour, and the necrotic areas become dry and brittle.

The necrotic stage is often preceded by a light green interveinal chlorosis affecting mature to older leaves, and often most obvious on the leaves of axillary shoots. Interveinal areas are pale green and are finely divided by the network of minor veins which retain a darker colour. In mild cases, this chlorosis may be the only visible symptom of disorder.

Magnesium deficiency

The earliest symptom of Mg deficiency is an interveinal chlorosis of older leaves (Fig. 4). In some cultivars, the chlorotic tissue progresses from pale green to pale yellow or golden; others yellow only as the leaf nears senescence. The darker green zones beside veins tend to be quite wide initially, narrowing as the symptom develops. In senescent leaves, the veins also lose their green colour. The chlorotic zones may remain as discontinuous patches between the secondary veins, or coalesce to form irregular strips between the main lateral veins. Chlorotic leaves become slightly wilted and hang near vertically, with the side margins curled upward. The oldest leaves eventually develop a soft, mid-brown, spreading necrosis in the chlorotic zones. Leaves are shed before becoming dry and brittle.

The occurrence of secondary pigmentation varies considerably among cultivars. Red pigment may develop on the minor veins on the lower leaf surface, or around the edge of chlorotic patches. In many instances, the older leaves develop a mottled orange–brown pigmentation of the upper epidermis, mostly over interveinal zones, and concentrated towards the tip of the blade.

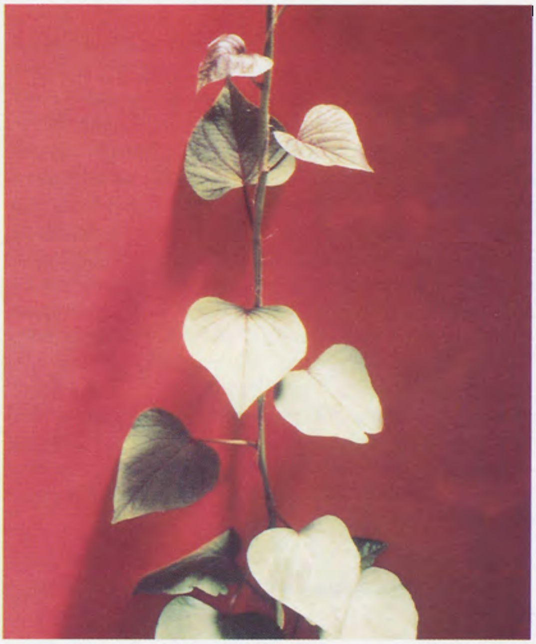

Fig. 1. Nitrogen deficiency in cv. Markham: general light green chlorosis and red pigmentation of veins on younger leaves.

Fig. 2. Phosphorus deficiency in cv. Hawaii: an older leaf with yellow interveinal patches becoming necrotic, and dark red-purple pigmentation of the leaf surface near the margins and tip.

Fig. 3. Potassium deficiency in cv. Markham: yellow chlorosis progressing to necrosis on marginal and interveinal zones of older leaves.

Fig. 4. Magnesium deficiency in cv. Wanmun: interveinal chlorosis on older leaves progressing from pale green to yellow, with upward curling of the leaf margins.

Boron toxicity

Boron toxicity causes conspicuous necrotic lesions in the interveinal areas of older leaves, leading to premature senescence and shedding of the leaves. Symptoms may be evident on plants suffering only a minor reduction in growth due to B toxicity. Affected leaves are usually cupped downwards, or curled under at the tip (Fig. 5).

Initial symptoms may be the development of a pale green to whitish chlorosis on the main interveinal areas, but in other cultivars necrotic spots may be preceded by only a slight localised chlorosis, with the surrounding tissue remaining green. When necrotic spots are within chlorotic zones, they are pale brown, but where they overtake green tissue, they display a dark rim. In some instances, the necrotic tissue may drop out, leaving 'shot-holes'.

Lesions are usually regularly distributed throughout interveinal tissue, but more concentrated near the margins. They may spread and coalesce to occupy most of the interveinal tissue. However, in some cultivars, the distribution may be less regular.

Leaves senesce by turning first yellow and then completely brown and dry before shedding.

Manganese toxicity

The first visible symptom of excess Mn is the appearance on older leaves of small, angular patches of pale tissue in the interveinal zones, indicating a localised tissue collapse. Subsequently small (0.5–2 mm), roughly circular spots of dark necrosis develop (Fig. 6). In contrast to the symptoms of B toxicity or salinity, the lesions are small and scattered within the main interveinal sectors of the leaf, rather than in a row midway between the main lateral veins. These symptoms may be associated with the blackening of minor veins on the lower side of the leaf. The lesions multiply and coalesce until they occupy most of the leaf area. Affected leaves eventually turn yellow and are shed.

Excess Mn inhibits the uptake of Fe by the plant. Uptakes of Ca and Mg are reduced to a lesser extent. The resulting deficiencies may have a more severe effect on plant growth than the excess Mn per se. Symptoms indicative of induced Fe deficiency are a pale yellow to white interveinal chlorosis of young leaves, and eventually a necrosis of the young leaves and the shoot apex, resulting in arrested growth.

Salinity

Sodium chloride (NaCl) salinity results in dark necrotic lesions on the older leaves, followed by rapid leaf senescence and abscission (Fig. 7). Discrete chlorotic or water-soaked zones may appear before necrotic symptoms in some cultivars; they are centred between the main veins and may be separate, irregularly shaped spots of approximately 3–10 mm diameter, or a continuous strip from near the midrib to the margin. Necrosis first appears on oldest leaves at the margins or the tips of lobes in divided leaves, from where it spreads into interveinal tissue. However, as the symptoms spread to younger leaves, necrosis may arise as discrete, well-separated lesions away from the margin, in the chlorotic zones if they are present, and forming a line down the centre of sectors between main veins. The tissue at the nuclei of lesions is generally paler than the necrosis which subsequently spreads between them. Leaf senescence proceeds with the spread of yellow chlorosis from the necrotic zones, and leaves become dry and shrivelled before they are shed.

In severe cases, the plant becomes slightly wilted and generally chlorotic, and older leaves may be abscised before the development of extensive necrosis. Necrosis of the stem may lead to the death of the shoot tip.

Disorders producing ymptoms on leaves of any age

Sulfur deficiency

Sulfur deficiency results in a uniform pale green chlorosis throughout the plant, together with severe stunting, a reduction in leaf size, and reduced activity of axillary buds. Veins do not retain green colour, and in less severe cases, they may be more chlorotic than the interveinal tissue. In cultivars in which young leaves are normally green (i.e. lacking red pigmentation), youngest leaves may appear chlorotic earlier or more severely than mature leaves (Fig. 8).

Red-brown pigmentation may develop in both young and old leaves. In cultivars with normally green tips, the petiole and margins of young leaves may become red, and this may extend in a mottled pattern across the upper epidermis. In the oldest leaves, a more diffuse pigmentation of the upper epidermis may extend over interveinal zones, but it is usually more concentrated around the leaf margins. Leaves of intermediate age generally lack red pigment.

The growth reduction and chlorosis of the whole plant closely resemble the symptoms of N deficiency. A useful distinguishing character is the red pigmentation of veins of young leaves in N-deficient plants. While S deficiency may increase pigmentation of young leaf margins and petioles, a strong veinal pattern is not typical.

Manganese deficiency

Usually the first sign of Mn deficiency in sweet potato is an indistinct interveinal chlorosis

Fig. 5. Boron toxicity in cv. Wanmun: necrotic lesions in the interveinal tissue of an older leaf, accompanied by downward curling of the tip and margins.

Fig. 6. Manganese toxicity in cv. Wanmun: small chlorotic patches and dark necrotic lesions on interveinal tissue of an older leaf, compared with a healthy leaf (top left).

Fig. 7. Salt stress in cv. Markham: interveinal necrosis progressing to complete senescence of older leaves, prior to leaf abscission. The relatively young leaves of the axial shoots are less affected.

Fig. 8. Sulfur deficiency in cv. Hawaii: general light green chlorosis compared with healthy leaves (left), and dark pigmentation of the margins of the youngest leaves.

throughout the plant, but particularly on leaves of intermediate age. The green zones around major veins are relatively broad and fade gradually toward the interveinal zone. In some cultivars, the contrast between veinal and interveinal zones may be slight, as the veinal tissue is also paler than in healthy leaves. Chlorosis may be accompanied by drooping of the leaves, slight puckering of the leaf surface or downward curling of the leaf margins. However, in contrast to copper (Cu) deficiency, which may also induce interveinal chlorosis and drooping, the drooping is caused by weakness of the petiole and is not accompanied by severe wilting of the leaves, nor does it progress to the point of leaf senescence and abscission.

On expanding leaves, small areas (approximately 1 mm diameter) between minor veins become pale and sunken, and eventually develop into necrotic spots (Fig. 9). While all interveinal zones of the leaf are affected, they do not develop at the same rate, and it is common to see a peppering of brighter cleared spots across the leaf blade. Initially, the leaves most affected are those which are rapidly expanding, a few nodes below the tip. But as the symptom intensifies, both older and younger leaves are affected. Pits in older leaves tend to be darker and are often concentrated adjacent to the base of the midrib and main veins. The young leaves become pale, thickened and brittle, and may curl under or buckle as they expand. When pitting occurs in very young leaves, their subsequent expansion causes the pits to develop into larger holes. In severe cases only a lacy skeleton of the leaf remains. Severely-affected leaves become necrotic, the necrosis spreading from the tip or lateral margins. The growing points at the tip and in leaf axes remain active. Axillary shoots are generally less affected than the subtending leaf.

Suspected cases of Mn deficiency can be confirmed by leaf painting with a 1% solution of $MnSO_4$, which causes regreening of chlorotic tissue, and in young leaves it arrests the development of interveinal pits and enhances expansion of the treated portion of the leaf blade.

Copper deficiency

Considerable growth reduction may be caused by Cu deficiency, producing thin, small-leafed vines. A number of visible symptoms have been observed, the extent and order of development of these varying among cultivars.

Chlorosis and drooping of mature leaves of intermediate age may be the first visible symptom of Cu deficiency (Fig. 10). The chlorosis is interveinal, with fairly wide, diffuse green zones around the major veins. Leaf margins tend to curl under, and leaves are slightly wilted and drooping. In some cultivars, particularly Wanmun, necrotic spots have been observed on old to intermediate-aged leaves. They may appear before or after the development of interveinal chlorosis, and do not necessarily affect the same leaves. Initially they are small, dark and sharply defined. They may be clustered close to the point of petiole attachment, or more commonly scattered over the entire leaf surface. Subsequently a yellow chlorosis develops around them, spreading to encompass a group of lesions. Later, the area between the initial lesions develops a russet necrosis. Complete senescence of the leaf follows.

Symptoms affecting the young leaves and growing point usually develop later than those described above, but in some cultivars they may be the only visible symptoms. Initially, the surface of young leaves may appear silvery (but not shiny), due to a change in the texture and reflectiveness of the leaf surface. At greater severity, leaf deformities occur. New leaves are very small and may be misshapen, puckered, or develop holes due to uneven expansion of the blade (Fig. 11). Some reduction in internode length is common. Unlike zinc (Zn) deficiency, narrowing and reduction in lateral lobes is not characteristic.

Zinc toxicity

Zinc toxicity may cause severe growth reduction or completely arrest the growth of transplanted cuttings. Specific visible symptoms include the development of dark pigmented spots or blotches on older leaves or increased red pigmentation of the leaf blades, particularly around margins and veins. Severe damage to the roots at high Zn concentration may cause general wilting, which is accompanied by chlorosis, with or without increased secondary pigmentation.

High levels of Zn inhibit the uptake of Fe, and it is common to find symptoms of severe Fe deficiency induced by Zn toxicity (Fig. 12). A pale yellow to white interveinal chlorosis develops in the younger leaves, and may eventually lead to necrosis of the leaf blades and growing point. Cultivars which normally have purple pigmentation in the youngest leaves become bright pink at the tip. Leaf painting with a 1% solution of $FeNH_4(SO_4)_2$ causes dramatic regreening of treated tissue, confirming that a lack of Fe is responsible for these symptoms.

Copper toxicity

Copper is highly toxic to sweet potato, concentrations as low as 5 µM in the root zone being sufficient to cause significant growth reductions. Concentrations above 20 µM may cause complete root death. Root damage results in severe wilting and

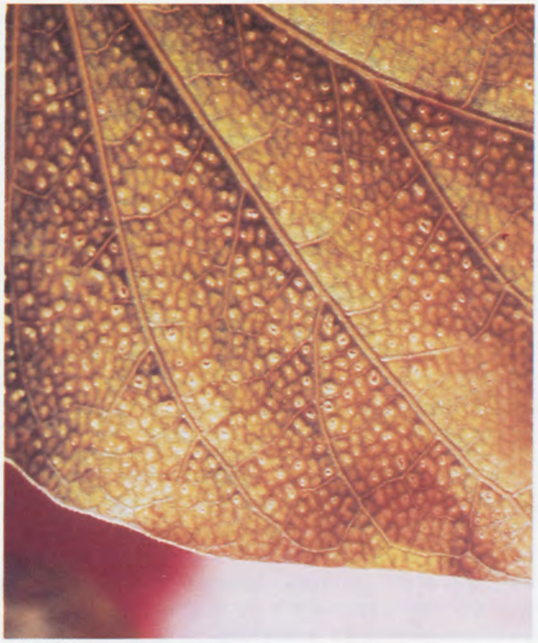

Fig. 9. Manganese deficiency in cv. Wanmun: small interveinal pits developing on a young expanding leaf.

Fig. 10. Copper deficiency in cv. Wanmun: interveinal chlorosis and wilting of leaves of intermediate age.

Fig. 11. Copper deficiency in cv. Wanmun: deformation of young leaves resulting in small size, puckering, and holes in the laminae from uneven expansion of tissue.

Fig. 12. Zinc toxicity in cv. Wanmun: pale chlorosis and some marginal necrosis on younger leaves due to induced iron deficiency, and dark pigmented spots along the veins on older leaves.

eventual death of the shoot tip. Unlike Zn toxicity, there is little or no general chlorosis of the leaves, nor increased red pigmentation.

Moderate levels of copper toxicity may be accompanied by a fine pale-green to white interveinal chlorosis on older leaves (Fig. 13). Small interveinal areas become pale and slightly sunken, while the tissue around the veins retains normal coloration. This symptom may be confused with the pitting caused by Mn deficiency, but it is most intense on older rather than younger leaves and is not accompanied by a general chlorosis of the leaf blade.

Aluminium toxicity

In strongly acid soils (less than pH 4.5), Al toxicity may cause severe damage to the roots. There are no specific symptoms in the tops other than those resulting from poor root function. Wilting was frequently observed, and in a number of instances a mild Mg deficiency developed.

Disorders producing symptoms mainly on the younger leaves

Calcium deficiency

The primary symptom of Ca deficiency is necrosis on young leaves. Necrosis spreads from irregular patches, especially along the lateral margins nearer the petiole, and extends inward mainly in interveinal tissue. Necrotic tissue is mid- to dark-brown and brittle, and necrosis is not preceded by chlorosis (Fig. 14). It is first seen on young expanding leaves, but as the disorder intensifies, newly-formed leaves are affected, and finally the apex may die. Necrotic leaves may be prematurely abscised. In the cultivar Hawaii, leaf drop is spectacular, leaving some length of bare stem below the tip. Other cultivars such as Wanmun and Markham may shed only a few leaves, or retain completely dry leaves on the stem. Root growth is poor, and severe cases suffer necrosis of roots.

Older leaves may develop necrotic spots, which are either clustered along the main veins from their origin to about half-way to the margin, or scattered uniformly across the interveinal areas, avoiding the central third of the blade. They are roughly round with abrupt, irregular edges, and do not seem to accelerate senescence of the leaf. These symptoms were also observed by Bolle-Jones and Ismunadji (1963) in the Indonesian cultivar Djarak. Another secondary symptom may be a pale green to white or pink chlorosis particularly on young leaves in full sun, due to inadequate Fe uptake resulting from poor root function under Ca deficiency.

Iron deficiency

The distinctive symptom of Fe deficiency is chlorosis of the youngest leaves. The chlorosis is a result of photobleaching of the photosynthetic pigments, and leaves in bright sunlight are more affected than those in shade. Initially, a yellow interveinal chlorosis develops, characterised by a sharply contrasting green network of veins. However, as the condition becomes more severe, the veins may lose their green colour and the entire leaf appears pale yellow or almost white (Fig. 15). While all the leaves of the plant may become affected, youngest leaves show the greatest intensity. However, if Fe supply is restored, new leaves will be bright green and chlorotic leaves may be found below them.

Severely-affected leaf blades become necrotic, usually spreading from the tip and margins into interveinal zones. Necrotic tissue is generally light brown and soft. Eventually, the growing points may die, both at the dominant apex and in axillary buds. Iron deficiency is common in alkaline soils, and may also be induced by a number of disorders which adversely affect root function. These include Ca deficiency and toxicities of Zn and Mn.

Boron deficiency

B deficiency affects actively growing tissue, both of the shoot and the roots. The first signs are a thickening and distortion of young leaves. Leaves become puckered (slightly raised in interveinal zones) and the leaf tip and lateral lobes typically curl under (Fig. 16). Leaves and stem near the shoot are brittle and break easily when bent. They are usually paler than the older leaves, but the extent and pattern of chlorosis is variable among cultivars. Internodes may be shortened, producing a close rosette of leaves around the apex. In severe cases, the leaf veins may appear callused or overgrown with rough whitish or pink tissue. Deeply-lobed cultivars such as Lole and Hawaii may display reduced development of the lateral lobes of the leaves.

The next phase is marked by the death of the growing points. The dominant tip is usually the first affected, but the axillary buds also become necrotic. Death of the shoot tip is precipitated by necrosis in the stem immediately below it.

Roots of B-deficient sweet potatoes become short, stumpy, and highly branched, producing the coralline structures typical of B deficiency in many species. The growth of adventitious root buds may be stimulated around the lower nodes of the stem.

Fig. 13. Copper toxicity in cv. Wanmun: pale yellow patches of interveinal chlorosis on mature to old leaves.

Fig. 14. Calcium deficiency in cv. Wanmun: necrosis of young leaf blades, and chlorosis and necotic spots developing on mature leaves.

Fig. 15. Iron deficiency in cv. Wanmun: young leaves are bleached almost white, or pink where anthocyanin pigments are present, while slightly older leaves display sharply-defined interveinal chlorosis.

Fig. 16. Boron deficiency in cv. Wanmun: youngest leaves are pale and puckered with margins curled downward; the growing point is dead.

Fig. 17. Zinc deficiency in cv. Wanmun: markedly reduced size of the youngest leaves, and interveinal chlorosis on older leaves.

Zinc deficiency

The most distinctive symptom of Zn deficiency in sweet potato is a reduction in size of young leaves. (Figure 17.) The leaves are thickened but usually not distorted, and may be no more than 1 to 3 cm in length. After the onset of this symptom, plant growth is severely limited. In some cultivars such as Markham and Hawaii, internodes are also shortened, but in others such as Wanmun, this occurs to a far lesser extent than the reduction in leaf size. General chlorosis of the young leaves is usual, but may vary from mild to almost complete bleaching. Characteristic changes in leaf shape are narrowing and repositioning of the lateral lobes (if present) which point forwards more acutely (subtending a sharper angle between the midrib and the main axis of the lobe).

Mature leaves develop an interveinal chlorosis in which both major and minor veins retain their green colour. The boundaries between veinal and interveinal zones are diffuse, and less developed cases will appear as a fine interveinal mottle. The symptom quite closely resembles mild K deficiency in some cultivars; however, unlike that caused by K deficiency, the oldest leaves are usually not the most severely affected. Interveinal chlorosis on mature leaves often precedes obvious signs of young leaf reduction.

Suspected cases of Zn deficiency can be confirmed by a positive response to painting the leaf surface with a solution of 0.5% $ZnSO_4$ with 0.25% $Ca(OH)_2$. After a few days, this should result in regreening of chlorotic tissue on either mature or young leaves, and increased expansion of the treated area of young leaves.

Acknowledgments

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References

Asher, C. J. and Blamey, F. P. C. 1987. Experimental control of plant nutrient status using programmed nutrient addition. Journal of Plant Nutrition 10, 1371–1380.

Bolle-Jones, E. W. and Ismunadji, M. 1963. Mineral deficiency symptoms of the sweet potato. Empire Journal of Experimental Agriculture 31, 60–64.

Clark, C. A. and Moyer, J. W. 1988. Compendium of Sweet Potato Diseases: Nutrient Deficiencies and Toxicities. APS Press, Minnesota USA, 61–63.

Hill, W. A. 1989. Sweet potato. In: Plucknett, D. L. and Sprague, H. B. ed., Nutrient Deficiencies in Tropical and Temperate Crops, Westview Press, USA, Ch. 18, 179–188.

Spence, J. A. and Ahmad, N. 1967. Plant nutrient deficiencies and related tissue composition of the sweet potato. Agronomy Journal 59, 59–62.

Diagnostic Criteria for Nutrition Disorders of Sweet Potato II: Critical Nutrient Concentrations in Leaves

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Abstract

Sweet potato cuttings (*Ipomoea batatas* cv. Wanmun) were grown in solution culture, and nutrition disorders were induced at a range of levels by varying the supply of each element relative to adequately supplied controls. After four weeks, plant dry weights were recorded and samples of leaf tissue analysed for nutrient composition. Entire blades of the 7th to 9th leaves were selected as the index tissue, on the basis of sensitivity, consistency of results, and ease of collection in the field. For each disorder, leaf nutrient concentrations were plotted against the relative growth of the plant, and critical nutrient concentrations derived. The selection of a procedure for estimation of critical nutrient concentrations is discussed.

THE diagnosis of a nutrition disorder begins with the observation of visible symptoms of stress in the crop. In many cases specific symptoms will be sufficient for an experienced observer to identify the problem. However, several disorders may produce similar symptoms, and the expression of symptoms may be modified by other environmental factors. Hence it is often necessary for a tentative diagnosis to be confirmed through chemical analysis of plant tissue or of the soil, or by the response of selected plants to the application of the nutrient suspected of being deficient. Soil analysis has two disadvantages: firstly, there are no practical soil tests for all essential elements, and, secondly, soil test correlations with growth, and soil test calibrations tend to be somewhat soil-specific and may break down when used on soils differing in mineralogy from that used when the test was developed. Plant response to nutrient application is particularly useful in the case of micronutrient deficiences, where painting a dilute solution on the leaf surface can result in spectacular recovery of the treated portion of the leaf. However, the method is qualitative and requires the crop to be monitored for a period of time after the nutrient application. Tissue analysis lacks these drawbacks, but useful interpretations require careful calibration of an index tissue against plant growth at a range of levels of supply of each nutrient to determine critical nutrient concentrations. It is equally important that standardised procedures are used for the selection and treatment of material collected from the field.

To date, no critical nutrient concentrations have been reported for sweet potato. Bolle-Jones and Ismunadji (1963) reported leaf concentrations associated with a number of nutrient deficiences. However, the sample analysed included all laminae of the plant, and only one deficient treatment was studied for each nutrient. A similar experimental design was used by Spence and Ahmed (1967), but tissue analyses reported were for whole tops. Leonard and co-workers (1948) applied a series of supply levels for each of a number of nutrient salts, and examined the changes in nutrient composition of plant tissues. However, they did not examine the relationship between tuber or vine yield and the concentration of the limiting nutrient.

The study reported here was intended to provide critical nutrient concentrations for sweet potato plants.

Method

The experimental design and procedure were described in the preceding paper. All data presented in this paper are from the cultivar Wanmun; analysis of data from other cultivars is not yet complete.

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Results and Discussion

Selection of an index tissue

The concentration of any nutrient is not uniform throughout the plant, but varies considerably with the type and age of the tissue. It is essential for accurate diagnoses that the sampled tissue corresponds as closely as possible to that for which the critical concentrations were defined.

The selected index tissue should be easily identified and collected in the field, and should also be a tissue which reflects the plant's status with respect to any given nutrient, through a significant change in the tissue nutrient concentration. Young leaves would be expected to be the most sensitive indicators of deficiencies of phloem-immobile elements such as calcium (Ca) or iron (Fe), while older leaves should show a greater concentration shift for deficiencies of mobile elements, and for mineral toxicities. Therefore in selecting a single tissue for diagnosis of any nutrition disorder, a compromise must be made.

In most cases, the selected tissue is a young but physiologically mature leaf. This is often identified as the youngest fully expanded leaf blade (YFEB). However, in sweet potato the expansion of leaves is a protracted process which does not seem to give a useful indication of physiological maturity.

In the process of selecting an index tissue for use in this study, measurements were made of the distribution of each nutrient among leaves of differing age, in both healthy plants and those suffering a deficiency or toxicity of that element. Whole leaf blades were sampled in groups of three, numbering from the youngest open blade on the main stem. A wide range of contrasting profiles was obtained, of which Figures 1(a) and (b) are examples. To compare the utility of different age groups for indicating a nutrition deficiency, the ratio between the concentration in a deficient plant and that in a healthy plant was plotted (Figures 1(c) and (d)). The lowest values correspond with the greatest sensitivity to nutrient stress. Plots for each of the nutrients tested were assessed to select a sample which responded adequately to all disorders. This process revealed that very young tissue was undesirable because its composition was rapidly changing, while older leaves were not sensitive indicators of some disorders. The selection of the 7th to 9th leaf blades was made on the basis that it corresponded to relatively low concentration ratios in all plots, the leaves were old enough that concentrations were not changing rapidly with age, and the sample was still relatively easily identified in the field.

Determination of critical nutrient concentrations

With the exception of molybdenum (Mo), variation in supply of the test element caused large variations in plant dry weights (see Figure 2 for examples).

For each disorder, a plot was obtained of the concentration of the test element in the index tissue and the whole plant dry matter yield, expressed as a percentage of the mean weight for non-limiting treatments (see Figure 3). A number of methods have been described in the literature for estimating critical nutrient concentrations from similar empirical data (Blamey and Mould, 1979). Most of the curves tended towards a plateau or asymptote in the range of sufficiency, as in Figure 3(a). Here exponential functions provided a good fit to the data, and the critical concentration may be taken as that corresponding with the 90% yield point on the curve (Smith 1986).

In some cases, as in Figure 3(b), a discontinuous linear function (Hudson 1966) provided a better approximation to the data than a smooth curve. Here, the critical nutrient concentration is taken as the point of intersection of the two linear functions. This is referred to as the 'broken stick' model.

In a few cases, as in Figure 3(c), luxury consumption did not occur within the plateau region of the curve relating yield to nutrient supply (compare Figure 2(c)). Here the concentrations in the index leaves remained approximately constant once the nutrient requirement of the plant had been satisfied. In such cases, the critical concentration has again been set at the 90% yield point, even though the fitted curves do not exhibit a plateau region.

Table 1. Tentative critical concentrations and adequate concentration ranges in the 7th to 9th leaf blades of sweet potato, for a number of nutrition disorders.

Disorder	Critical concentration	Adequate range
Deficiency		
N (%)	4.2[b]	4.3–5.0
P (%)	0.22[c]	0.26–0.45
K (%)	4.0[c]	4.7–6.0
Ca (%)	0.76[a]	0.90–1.2
Mg (%)	0.12[a]	0.15–0.35
S (%)	0.34[b]	0.35–0.45
Fe (mg/kg)	33[c]	45–80
B (mg/kg)	40[c]	
Mn (mg/kg)	19[c]	26–500
Zn (mg/kg)	11[c]	12–40
Toxicity		
Mn (mg/kg)	1600[c]	26–500
Zn (mg/kg)	85[c]	12–40

[a]Estimation by the exponential model; [b]by regression analysis; [c]by the broken stick model

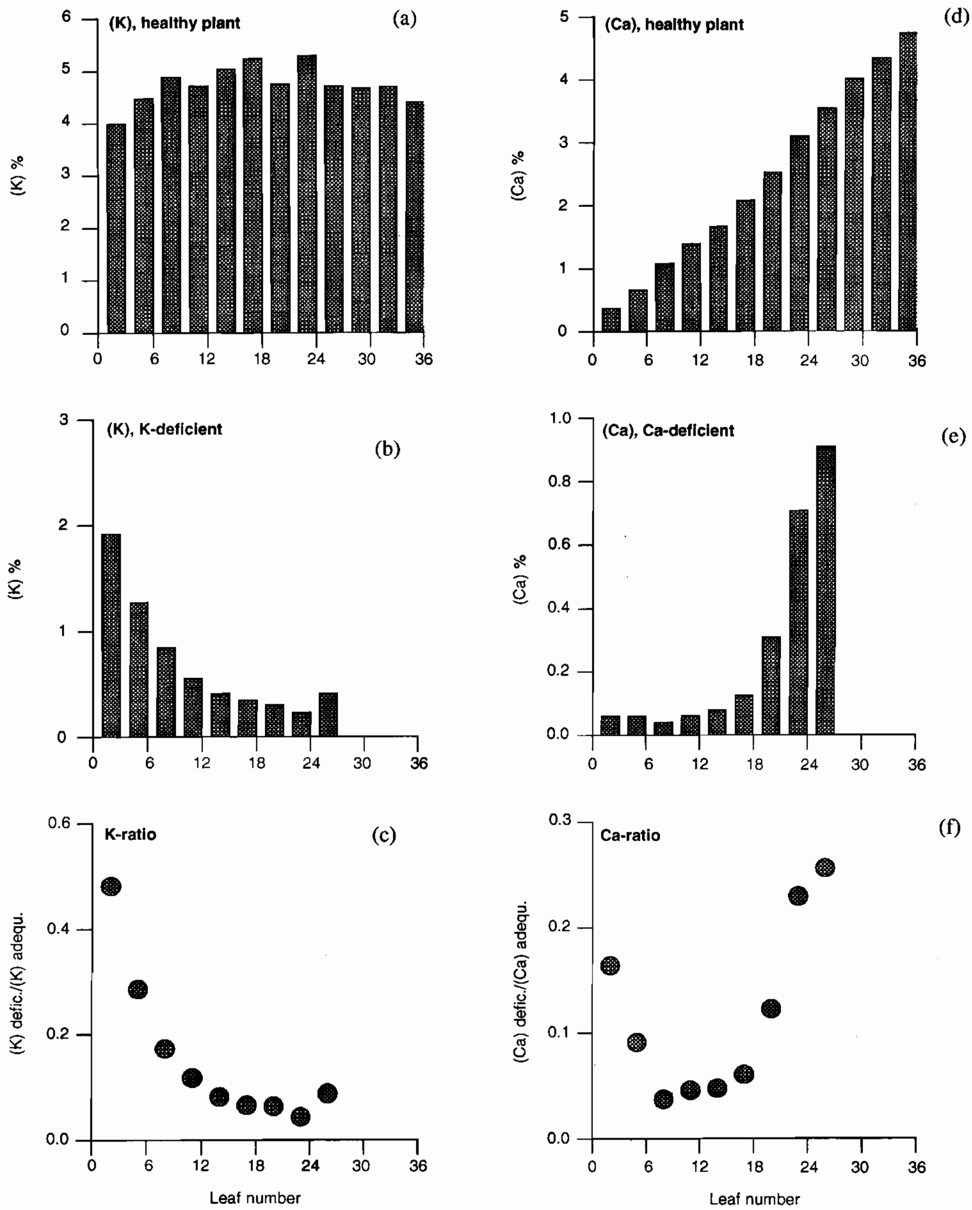

Fig. 1. The change in concentration of K (a)–(c) and Ca (d)–(f) in sweet potato leaves with leaf position, from the youngest open blade to the oldest on the main stem. Concentrations are given for leaves of healthy plants ((a) and (d)) and plants deficient in K and Ca ((b) and (e), respectively). The concentrations in deficient and healthy plants are compared in (c) and (f).

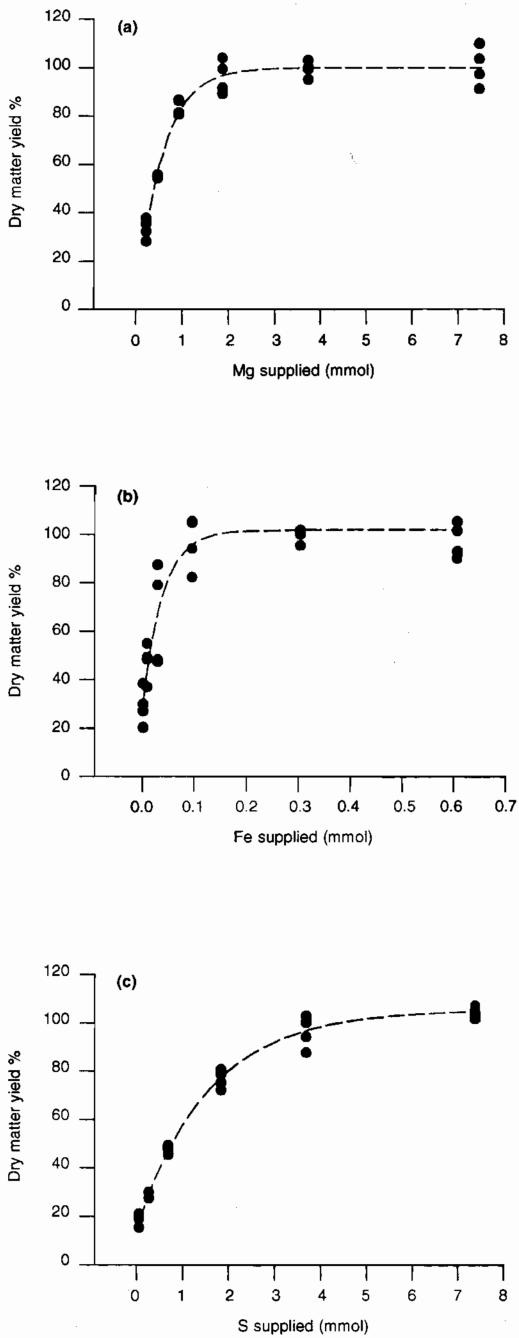

Fig. 2. Relationships between the relative dry matter yields of sweet potato plants and the supply of (a) Mg, (b) Fe and (c) S.

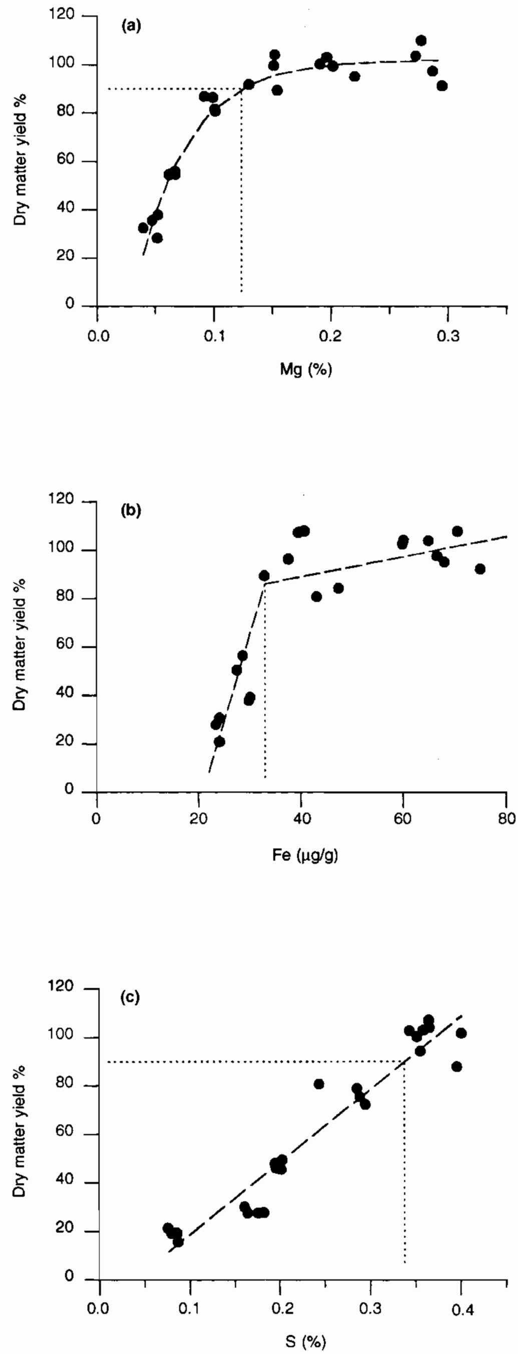

Fig. 3. Relationships between the relative dry matter yields and the concentrations in the index tissue of (a) Mg, (b) Fe and (c) S across a range of supply levels. Critical concentrations were estimated using (a) an exponential function model, (b) regression and (c) the 'broken stick' procedure.

Table 1 shows the critical concentrations obtained by the methods described above. These values are regarded as tentative, as the data from multi-cultivar experiments has not been included. As critical concentrations obtained with glasshouse-grown plants sometimes differ somewhat from those of field-grown plants, these values should be field-tested, where possible, before their use is recommended.

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References

Blamey, F.P.C. and Mould, D. 1979. Evaluation of response functions for establishing the critical boron concentration in sunflower leaf tissue. Gewasproduksie/Crop Production 8, 171–174.

Bolle-Jones, E.W. and Ismunadji, M. 1963. Mineral deficiency symptoms of the sweet potato. Empire Journal of Experimental Agriculture 31. 60–64.

Hudson, D.J. 1966. Fitting segmented curves whose join points have to be estimated. Journal of the American Statistical Association 61. 1097–1129.

Leonard, O.A., Anderson, W.S. and Gieger, M. 1948. Effect of nutrient level on the growth and chemical composition of sweet potatoes in sand culture. Plant Physiology 23. 223–235.

Smith, F.W. 1986. Interpretation of plant analysis: concepts and principles. In: Reuter, D.J. and Robinson, J.B. ed., Plant Analysis — An Interpretation Manual. Inkata Press, Australia.

Spence, J.A. and Ahmad, N. 1967. Plant nutrient deficiencies and related composition of the sweet potato. Agronomy Journal 59. 59–62.

Pot Experimentation to Study Nutrient Responses of Sweet Potato in Papua New Guinea

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Abstract

Omission pot trials with maize (*Zea mays* L.) identified deficiencies of phosphorus (P) and sulfur (S) in Orthoxic Tropudult and Umbric Tropaquult soils at Aiyura in the Eastern Highlands of Papua New Guinea. Sweet potato (*Ipomoea batatas* (L.) Lam.), however, is the major crop of the area, and information is not available on this crop's response to applied P and S. In glasshouse experiments, sweet potato was shown to have potential as a test species provided water stress was minimised. Sweet potato was shown to be strongly mycorrhizal, with growth responses to P severely limited in the absence of infection. Growth responses of infected plants on the Orthoxic Tropudult soil allowed calculation of P and S requirements for 90% of maximum yield as 48 and 25 kg/ha, respectively. Further experimentation on the role of vesicular-arbuscular mycorrhizae in sweet potato nutrition is suggested, and data are required describing growth responses to plant-available P and S in glasshouse and field experiments.

SWEET potato (*Ipomoea batatas* (L.) Lam.) is the most important staple food crop grown at the village or smallholder level in Papua New Guinea (PNG) (Bourke 1985). However, its nutritional requirements are little understood. Pot experiments using a variety of test species on soils from the Gazelle Peninsular of New Britain have shown responses to P, nitrogen (N), potassium (K), magnesium (Mg) and manganese (Mn) (Bourke 1977). Pot experiments with tomato (*Lycopersicon esculentum* L.) on volcanic ash soils from this region have shown dramatic growth responses to P, but without corresponding responses in the field. Research in the Highlands of PNG has shown only moderate tuber yield increases to P, even in cases where soils are highly P-fixing and foliar analysis suggested P deficiency. Also, inconsistent tuber responses to N are common, with positive responses in some cases and negative responses in others; top growth, however, always increased with N-fertilizer application (Bourke 1985).

At the village or smallholder level, sweet potato gardens are managed according to traditional shifting cultivation practices. These practices typically include a period of fallow with grass or woody regrowth. The effective lifespan of a garden soil depends upon its initial physical and nutrition status, and upon the rate of physical and nutrition degradation under cropping. In parts of Enga and Southern and Western Highlands Provinces, the productive life of a garden may be extended by use of organic manures, but rarely by application of inorganic fertilizer or by use of soil amendments (e.g. mulch, lime). In the Eastern Highlands, peanut (*Arachis hypogaea* L.) and winged bean (*Psophocarpus tetragonolobus* L. CD.) are often planted in rotation with sweet potato, with up to 20% of new plantings devoted to these legumes annually (Bourke 1990).

The Department of Agriculture, PNG University of Technology has directed its efforts toward understanding the nutrition constraints in sweet potato production in smallholder farming systems. In the villages, there is ever-increasing pressure on traditional agricultural land, such that fallow periods are decreasing and soil nutrition reserves are

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degrading. Poor yield due to one or more nutrition disorders results in a poor return relative to inputs (e.g. labour). Hence the identification and correction of disorders could be of considerable benefit to farmers. Studies completed in collaboration with the PNG Department of Agriculture and Livestock, The University of Queensland, the Australian Centre for International Agricultural Research (ACIAR), and the International Board for Soil Research and Management (IBSRAM) have included omission pot experiments with maize (*Zea mays* L.), a pot experiment to assess sweet potato as a test species, and pot experiments to describe the response of sweet potato to applied P and S.

Background

The IBSRAM *PACIFICLANDS* Project site on the Highlands Agricultural Experiment Station at Aiyura in the Eastern Highlands was established to: (i) quantify soil loss and fertility decline under improved and traditional farming practices; and (ii) demonstrate how improved farming practices can reduce soil loss and maintain soil fertility, thereby extending the productive life of village gardens sown to sweet potato (Wayi and Konabe 1993). To help meet these objectives, omission pot trials using surface (0–0.15 m) soils with maize (Grundon 1987) were conducted to identify nutrition disorders as these may initially limit crop growth, which in turn may be a factor influencing the rate of soil loss.

The soil survey of the IBSRAM site identified two dominant soil types: (i) Orthoxic Tropudult soils on north-facing slopes; and (ii) Umbric Tropaquult soils on south-facing slopes (Wayi and Konabe 1993). The surface Orthoxic Tropudult and Umbric Tropaquult soils have similar properties, both soils being strongly acid (pH 5.0–5.4, 1:5 soil:water) with low levels of soluble salts. Olsen-P levels are low (<4 mg/kg) and soils are strongly P-fixing, suggesting probable crop responses to P fertilizer. Organic C, total N, Cation Exchange Capacity (CEC) and exchangeable Ca, Mg and K levels are medium to high and exchangeable Na is low. Soils are 25–37% base saturated with low effective CEC (<10 cmol(+)/kg). Exchangeable acidity (<1.2 cmol(+)/kg) and acid saturation levels (13–16%) suggest only Al-sensitive crops are likely to be affected. Lime (5 t/ha) may need to be applied to raise pH above 5.5, but care should be taken to avoid micronutrient deficiencies or cation imbalance through over-liming.

Omission Pot Experiment with Maize

Procedure

Procedures given by Asher and Grundon (unpublished report) were followed (Dowling et al. 1994). The control treatment was the complete nutrient or ALL treatment. For the ALL treatment, nutrients were applied separately at the following rates (kg/ha): 100 N; 80 P; 80 K; 35 Ca; 30 Mg; 25 S; 5 Fe; 2 B; 4 Zn; 5 Mn; 3 Cu; 0.4 Mo; and 0.1 Ni. Omission treatments were then arranged to omit only one element (e.g. ALL minus N, ALL minus P, ALL minus K). An additional ALL plus lime treatment was included with 5 t/ha lime (as $CaCO_3$).

After 7 days of the soils being watered to field capacity (FC), six germinated maize seeds were planted in each pot, and thinned to four uniform plants per pot after emergence. Pots were watered daily to FC with distilled water. Plants were grown until well-defined growth responses were evident 35 days after sowing (DAS). Plant tops were harvested at ground level, then dried (70°C for 48 hours) and weighed. Plant top dry weight data were expressed relative to the mean of the ALL (=100%) treatment. Omitted nutrient effects were determined by two-sample t-test by comparing each omission treatment in turn with the ALL treatment.

Results and Discussion

Similar maize growth responses to omission treatments were observed on both soils. From about 17 DAS, plants in the ALL minus P pots were visibly smaller than those in the ALL pots. There were no distinct symptoms other than a mild purple discoloration of the leaf sheaths similar to that reported by Grundon (1987) as indicative of P deficiency. From the same time, ALL minus S plants were visibly smaller and distinctly chlorotic. This chlorosis uniformly affected the whole plant (i.e. young and old leaves and stems were yellow) with some reddening of stems, and the tips of older leaves became necrotic.

At harvest, mean dry top weight in the ALL treatment was 3.33 and 4.14 g/pot in the Orthoxic Tropudult and Umbric Tropaquult soils, respectively. Significant reductions in weight of dry tops were observed for both soils where P or S had been omitted. Relative to the ALL treatment, mean dry top weight was 19% and 26% lower for ALL minus P, and 15% and 43% lower for ALL minus S in the two soils (Table 1). Dry top weight in the other treatments was not significantly different from that in the ALL treatment.

Both P and S appear limiting in both soils, and deficiencies are likely but not certain to occur in the field. These results suggest poor nutrition and soil loss may act in combination to decrease crop productivity over time. Effects due to soil loss alone will be difficult to quantify, but omission experiments may be repeated in time to determine whether the severity of P and S deficiencies have increased and if other nutrients have become limiting.

Table 1. Plant top dry weight data for P and S omission treatments (expressed relative to the ALL treatment = 100%) for Orthoxic Tropudult and Umbric Tropaquult soils from Aiyura in the Eastern Highlands of PNG.

Treatment	Plant top dry weight data (with standard error) expressed relative to the ALL treatment (=100%)			
	Orthoxic Tropudult		Umbric Tropaquult	
ALL	100	(4.2)	100	(2.6)
ALL minus P	81	(2.0)*	74	(4.4)*
ALL minus S	85	(3.3)*	57	(10.0)*

* values in the same column are different ($P<0.05$) from the ALL treatment

Preliminary Pot Experiments with Sweet Potato

Background

Having identified those nutrients potentially limiting crop production, fertilizer rate trials are required to establish the quantity of nutrients that should be applied. As species differ in their response to fertilizer application, it is preferable to use those crops to which the recommendations will apply. Sweet potato has been used in field (e.g. Bourke 1985, 1990; Wayi and Konabe 1993), controlled environment (e.g. Bourke 1977) and solution culture (e.g. O'Sullivan et al. 1993) experiments, but has not been used in short-term experiments with small volumes of soil. As a result, factors and amendments likely to modify sweet potato growth in small pots were investigated under controlled conditions.

Procedure

Using the Orthoxic Tropudult soil, a simple short-duration pot study was conducted to describe sweet potato growth responses to water (i.e. limited water, W_L; adequate water, W_A; and excess water, W_E), increased nutrient supply (Nutr), reduced soil acidity (Lime) and soil salinity (Salt). These factors were combined to give the following nine treatments: (1) W_L; (2) W_L+Nutr; (3) W_L+Nutr+Lime; (4) W_A; (5) W_A+Nutr; (6) W_A+Nutr+Lime; (7) W_A+Nutr+Salt; (8) W_E; and (9) W_E+Nutr. Complete details are given elsewhere (Dowling et al. 1995).

Nutrients (kg/ha) (200 N, 160 P, 130 K, 50 Ca, 75 S), lime (2.3 t/ha as $CaCO_3$ which increased soil pH from 5.2 to 5.8), and salt (6.5 t/ha as NaCl which increased soil Electrical Conductivity (EC) to 1.87 dS/m) were applied to appropriate treatments. Soil in the pots was watered to FC with distilled water and sealed. After 10 days, two sweet potato (cv. Wanmun) vine tip cuttings were planted in each pot. Pots were then watered with distilled water as required: viz. W_E pots were maintained at more than 66% available water capacity (AWC) by daily watering to saturation; W_A pots at 49–71% AWC by daily watering to FC; and W_L pots at 43–71% AWC by twice-a-week watering to FC. After 42 days growth, plant tops were cut at ground level, dried (70°C for 72 hours) and weighed. A soil sample was taken from each pot, dried at 40°C, sieved at less than 2 mm, and analysed for pH and salinity (EC 1:5 soil:water). Analysis of variance was used to test treatment effects on dry top weight.

Assessment of water and nutrient stress, soil acidity and soil salinity

Visible growth responses to treatments were apparent from about 10 DAS. Vines in W_E pots were the longest and greenest, whereas those in W_A+Salt and W_L pots were the shortest. Water stress appeared to limit vine growth more severely than did nutrient stress (previously identified as P and S deficiency) or soil acidity. The presence of a high level of salt (NaCl) dramatically reduced growth. Visible symptoms of P and S deficiency, as described by O'Sullivan and co-workers (1993), were not observed.

The impact of water stress on dry matter production was dramatic (Fig. 1). As water stress increased (and other stresses were not limiting; viz. W_E+Nutr < W_A+Nutr < W_L+Nutr), mean vine dry top weight decreased from 5.33 to 2.20 g/pot. As nutrient stress increased, dry top weight decreased from 5.33 to 4.43 g/pot (W_E+Nutr > W_E), but as water stress increased the impact of nutrient stress on dry matter production became less apparent. Addition of lime, although raising soil pH from 5.3 to 5.8, had little effect on dry matter production. But the effect of salinity (EC 1.87 dS/m) on plant growth and dry matter production was dramatic, and perhaps more pronounced than for water stress. With adequate water and nutrition, salinity markedly depressed dry matter production (W_A+Nutr > W_A+Nutr+Salt) from 4.3 to 0.74 g/pot. Clearly, sweet potato was unable to tolerate this high level of soil salinity, and further work may be warranted.

This study showed sweet potato has potential as a test species in short duration glasshouse studies.

However, limitations on plant size and period of growth imposed by small volumes of soil need to be recognised. In particular, it will be crucial to control and maintain soil water within defined limits (viz. FC to 50% FC) if other factors are to be studied effectively.

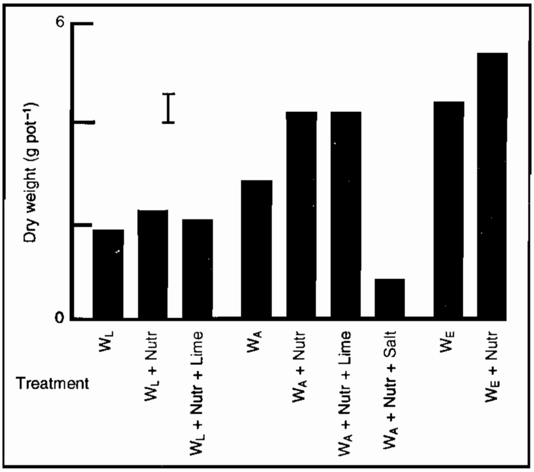

Fig. 1. Effect of water and nutrient stresses, soil acidity and soil salinity on sweet potato dry top weight where W_L = limited water supply, W_A = adequate water supply, W_E = excess water supply, Nutr = added nutrients, Lime = added lime, and Salt = added NaCl. Vertical bar shows least significant difference at $P<0.05$.

Response of Sweet Potato to P and S

Background

Once it had been established that sweet potato is an effective test species in glasshouse studies, it was possible to study the response of this species to applied P and S which had been shown to reduce maize growth in omission pot trials. These studies were used also to estimate P and S requirements for 90% of maximum yield (Y_{MAX}) and to evaluate the importance of vesicular-arbuscular mycorrhizal fungi in enhancing P uptake from these P–deficient soils.

Procedure

Two experiments were conducted, treatments consisting of seven rates of P or S (0, 20, 40, 80, 160, 320 and 640 kg/ha) on the Orthoxic soil. With P, two levels of mycorrhizal infectivity (plus and minus) were also assessed. In non-mycorrhizal treatments, soil at FC was incubated at 60°C for 48 hours to minimise potential for mycorrhizal infection of sweet potato roots. Basal P or S (160 kg/ha) was applied as required. Soil in pots was watered to FC with distilled water and sealed. After 10 days, two sweet potato (cv. Wanmun) vine tips were planted in each pot, and thinned to one vine per pot 7 DAS. Pots were watered daily to FC with distilled water. Vines were grown for 28 days when well-defined growth responses were evident. Vines were harvested and dry top weight determined. Root samples from zero P and zero S treatments were assessed for mycorrhizal infection after the method of Middleton and colleagues (1989). Mitscherlich equations were fitted to data describing dry matter yield of plant tops and applied P or S, and P and S requirements for 90% Y_{MAX} calculated.

Response to Applied P and S

In mycorrhizal soils, root infection levels ranged from 17 to 27% in zero P and from 17 to 24% in zero S pots with 160 kg/ha basal P. In contrast, infection levels ranged from 0 to 4% in non-mycorrhizal soils.

The application of P and S had similar effects on dry top weight and there was a significant P by mycorrhiza interaction (Fig. 2). In the mycorrhizal soil (including S pots), mean dry top weight increased from 1.50 to 3.53 g/pot, Y_{MAX} being estimated as 3.32 ± 0.12 g/pot and P and S requirements for 90% Y_{MAX} as 48 and 25 kg/ha, respectively. In the non-mycorrhizal soil, however, mean dry top weights were similar (range: 1.76 to 2.49 g/pot), Y_{MAX} was assumed to be the mean (2.07 g/pot), and it was not possible to estimate the P requirement for 90% Y_{MAX}.

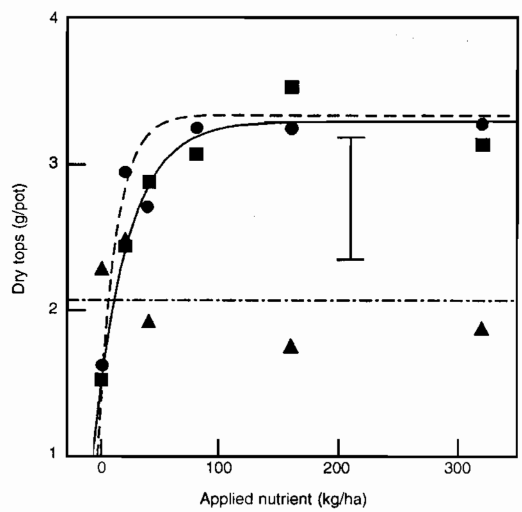

Fig. 2. Mitscherlich fits to data describing the relationship between yield of dry tops and applied P (solid line) and applied S (dashed line) in mycorrhizal soils and applied P (dash-dot line) in non-mycorrhizal soils for sweet potato grown in an Orthoxic Tropudult soil from Aiyura. (For convenience, data for 640 kg/ha additions of P and S are not included.)

Fertilizer rate experiments with sweet potato in pots confirmed P and S deficiency observed in maize in this Orthoxic Tropudult soil, and suggested P and S requirements for 90% Y_{MAX} of 48 and 25 kg/ha, respectively. The importance of mycorrhizae in enhancing P uptake from this P-deficient soil was demonstrated. Further experimentation is required into the role of vesicular-arbuscular mycorrhizae in sweet potato nutrition.

Conclusions

The ultimate test of a nutrient disorder is to demonstrate its correction in the field, and the focus of further research should be on the field confirmation of observed P and S disorders. Calibration of growth responses, particularly tuber yield, with soil and plant analyses for P and S are required also. Understanding these relationships will improve diagnosis of disorders associated with P and S supply, and will provide a sound basis upon which to assess the nutrition degradation of these soils over time.

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References

Asher, C.J. and Grundon, N.J. Unpublished report. Diagnosis of nutritional limitations to plant growth by nutrient omission pot trials. Department of Agriculture, The University of Queensland, Brisbane, Australia.

Bourke, R.M. 1977. Sweet potato (*Ipomoea batatas*) fertilizer trials on the Gazelle Peninsular of New Britain. Papua New Guinea Agricultural Journal, 28. 73–95.

— 1985. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. Papua New Guinea Agriculture Journal, 33. 90–108.

— 1990. Subsistence food production systems in Papua New Guinea: old changes and new changes. In: D.E. Yen and J.M.J. Mummery, ed., Pacific Production Systems: Approaches to Economic Prehistory. Occasional Papers in Prehistory No. 18. Department of Prehistory, Australian National University, Canberra. 148–160.

Dowling, A.J., Blamey, F.P.C. and Hoa, T. 1995. Limitations to sweet potato growth in small volumes of soil imposed by water and nutrient stress, acidity and salinity. Papua New Guinea Journal of Agriculture, Forestry and Fisheries 38 (in press).

Dowling, A.J., Konabe, B. and Tigat, R. 1994. Nutritional assessment of steeply sloping soils from Aiyura in the Eastern Highlands of Papua New Guinea. Papua New Guinea Journal of Agriculture, Forestry and Fisheries, 37. 23–29.

Grundon, N.J. 1987. Hungry crops: A guide to nutrient deficiencies in field crops. QDPI Information Series Q187002. Department of Primary Industries, Brisbane. 1–246.

Middleton, K.J., Bell, M.J. and Thompson, J.P. 1989. Effects of soil sterilization, inoculation with vesicular-mycorrhizal fungi and cropping history on peanut (*Arachis hypogaea* L.) growth in an oxisol from subtropical Australia. Plant Soil, 117. 41–48.

O'Sullivan, J.N., Asher, C.J., Blamey, F.P.C. and Edwards, D.G. 1993. Mineral nutrient disorders of the Pacific: preliminary observations on sweet potato (*Ipomoea batatas*). Plant Soil 155/156. 263–267.

Wayi, B.M. and Konabe, B. 1993. Site characterisation and implementation of the experiment at Aiyura, Eastern Highlands Province, Papua New Guinea. In: P. Pushparajah, ed., The Management of Sloping Lands in the South Pacific Islands (IBSRAM/PACIFICLANDS). IBSRAM Network Document No. 7. Bangkok, International Board for Soil Research and Management. 83–92.

The Use of Pot Experiments to Assess the Chemical Fertility of Selected Soils of Western Samoa

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Abstract

Nutrient omission pot trials were carried out to determine nutrient deficiencies in soils collected from five locations (Laloanea, Alafua, Salani, Afiamalu and Tapatapao) of Upolu Island in Western Samoa. Each location had two sites; continuously cropped (CC) and recently cleared (RC) except for Alafua which had only the CC site. The soil test values indicated low levels of N and P for CC sites, while exchangeable K values were low also in some RC sites.

The pot trial results revealed that two RC sites (Tapatapao and Salani) were not deficient in any of the elements studied. In the Laloanea RC site, N and P were deficient. The Afiamalu RC site showed N, P, K, Fe, Mn, Mo and Co deficiencies, while Alafua showed deficiencies of N, P, K, Mg, Cu and Ni. The Salani site showed deficiencies of N, P and Co. Both Tapatapoa and Laloanea (CC) sites showed deficiencies in N and P.

Soil test values and the results of pot trials were in general agreement for major nutrient elements but the micronutrients require further investigation.

THE missing element technique in pot experiments may give three types of information: (i) which elements are deficient, (ii) the relative importance of the deficiencies, and (iii) the rate at which fertility is depleted with successive cuttings when a pasture indicator crop is used (Chaminade 1972). Sanchez (1976) reported that soil test correlations in the greenhouse are useful when comparing extractants and determining tentative critical values. He emphasised that definite critical levels for soil tests as well as plant analysis can be established only through field trials.

Asher and Grundon (1991) reported that nutrient omission or missing element trials provide a cost-effective method of diagnosing nutrition limitations in soils. This method has been found useful in many parts of the world, including countries of Africa and Latin America (Sanchez 1976) Australia (Andrew and Fergus 1964) and Thailand (Chairatna et al. 1986).

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Not much work has been done on Samoan soils, especially in relation to micronutrient requirements. The present study was specifically carried out to determine the deficient elements of selected soils of Upolu Island in Western Samoa with a view to recommending a farmer-acceptable fertilizer program for sustainable taro production.

Research Objectives

The research objectives were to:

(i) identify the main nutrition factors limiting crop growth in some selected soils of Upolu Island using nutrient omission technique;

(ii) determine the optimum nutrient requirements through rate trials; and

(iii) compare soil test values (using standard techniques of USP Alafua Soils Laboratory) with the results using nutrition omission techniques.

Materials and Methods

Five locations (Laloanea, Tapatapao, Alafua, Afiamalu and Salani) having different rainfall regimes were selected for soil sampling (Fig. 1). Each location had two sites, recently cleared (RC)

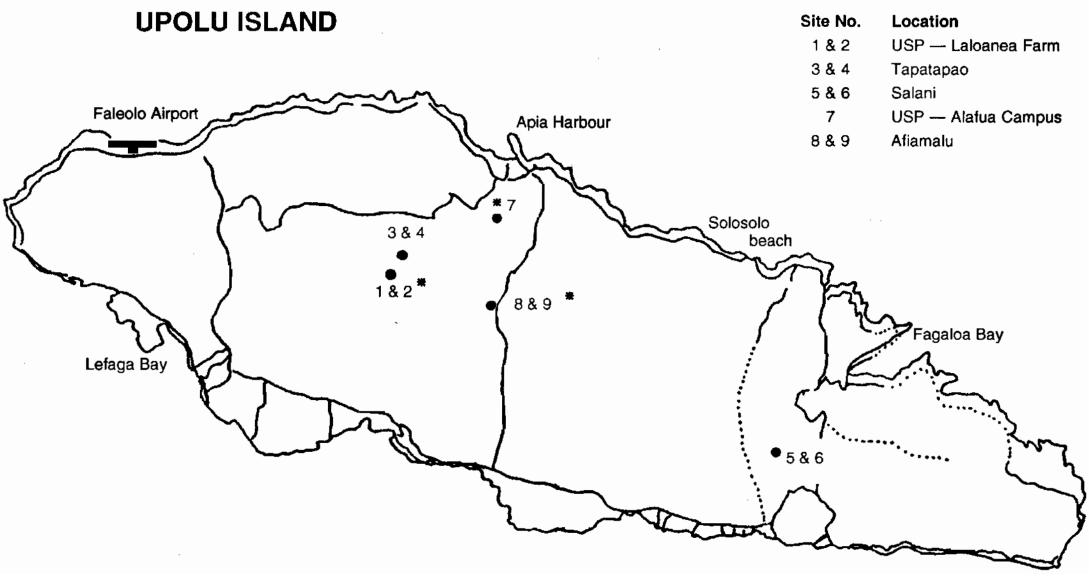

Fig. 1. Map showing the locations of the selected sites.

and continuously cropped (CC) except for Alafua which had only an RC site. The basic soil physical and chemical properties and the soil test values were determined by the methods described by Blackmore et al. (1987).

Preliminary and main nutrient omission pot trials were conducted following the method of Asher and Grundon (1991). The treatments were applied with the soil pH unamended because all soils were above pH 5.2. In the preliminary trials, six rates of standard nutrient addition (0, All 0.5, All 1, All 2, All 3, All 4) were used (see Table 1 for All 1 treatments and nutrient elements tested).

In the main omission pot trials, the best rates determined from the corresponding preliminary trials were used as the basal application of nutrients. The preliminary pot experiments had two replications of each treatment while in the main pot experiment, the 'All' treatment was replicated eight times and the other treatments four times (Andrew and Fergus 1964). The experiments were laid out in a completely randomised design. Since the experimental design of the main pot trial was unbalanced, having eight replications for the 'All' treatment and only four for each of the other treatments, the simplest method of statistical analysis was to compare each

Table 1. Typical rates of addition of elements and salts in the 'All' treatment.

Solution No.	Element	Rate of application of element (kg/ha)	Compound	Molecular weight	Weight conversion factor (elem. to salt)	Rate of application of salt kg/ha	Rate of application of salt mg/15 cm dm. pot	Concentration of stock solution (g/l)
1	P	30	NaH_2PO_42HO	178.00	5.75	173	314	62.8
2	K	80	KCl	78.56	2.01	161	293	58.6
3	Ca	35	$CaCl_2$	112.00	2.79	98	179	35.7
4	Ca	30	$MgCl_26H_2O$	203.3	8.35	250	455	91.0
5	S	25	Na_2SO_4	142.0	4.42	111	202	40.4
6	Fe	5	Sequestrene 138	—	16.7	100	182	36.4
7	B	2	H_3BO_3	61.84	5.72	11.4	20.7	4.14
8	Zn	4	$ZnCl_2$	136.3	2.08	8.34	15.1	3.02
9	Mn	5	$MnCl_2.2H_2O$	179.9	3.27	16.35	29.8	5.96
10	Cu	3	$CuCl_22H_2O$	170.5	2.68	8.04	14.6	2.92
11	Mo	0.4	$(NH_4)_6Mo_7O$	1236	12.88	5.15	9.37	1.87
12	N	100	$(NH_4)NO_3$	80.04	2.86	286	521	104.02
13	Co	0.1	$CoCl_26H_2O$	237.95	4.04	0.404	0.735	0.15
14	Ni	0.1	$NiCl_26H_2O$	237.72	4.05	0.405	0.737	0.15

treatment in turn, using a 't' test, with the 'All' treatment.

Using the soils of Afiamalu CC site, three rate trials were conducted, the elements tested being N, P, K, Fe, Mn, Zn, Mo and Co. For the soils of Alafua CC site the elements tested were N, P, K, Mg, Cu and Ni. For the Tapatapao soils it was decided not to continue any further pot or field trials since these soils showed identical (basic) physical and chemical properties and almost similar nutrient deficiencies to Laloanea soils.

Results and Discussion

The textural classes of the soils ranged from silty clay to silty clay loam (data not presented). The Permanent Wilting Point (15 Bar) water content of the nine sites showed fairly high values ranging 41–45%, while available water content ranged from 7% (Alafua site) to 14% (Tapatapao-RC site). The lowest pH (H_2O) values (5.2) were shown by high rainfall areas (Salani and Afiamalu) while the highest value (6.2) was recorded at relatively low rainfall sites (Alafua and Laloanea). All the CC sites were at least 0.1 to 0.4 pH units lower than RC sites. The pH (KC1) values were 0.4 to 1 units lower than the corresponding pH (H_2O) values. Soils from the CC sites contained relatively low concentrations of organic carbon (3.4–3.9%) and total N, while the RC sites had fairly high values for C (6–9%). Cation Exchange Capacity (CEC) values were low to moderate, and the exchangeable bases and Modified Troug P values of the cropped sites were low to marginal.

The nutrient omission pot trials revealed that two RC sites (Tapatapao and Salani) were not deficient in any of the elements studied (Table 2). For the soils of Laloanea RC site, N and P were deficient, while in the Afiamalu RC site, P and K showed deficiencies.

Among CC sites, deficiencies were shown for many macro- and micronutrients (Table 2). The Afiamalu site showed deficiencies of N, P, K, Fe, Mn, Mo and Co, while the Alafua site had deficiencies of N, P, K, Mg, Cu and Ni. The Salani site indicated deficiencies of N, P and Co. The Tapatapao and Laloanea sites were both deficient in N and K.

The rate trials were repeated three times to confirm the results of the most deficient Afiamalu CC site. The results showed some variation. However, based on the average values, the following optimum levels of nutrients were identified: nitrogen approximately 250 kg/ha, phosphorus more than 640 kg/ha, and potassium approximately 450 kg/ha. For micronutrients, the optimum levels were as follows: Mn 10–20 kg/ha; Fe 5–10 kg/ha; Mo 1.6–3.2 kg/ha and Zn 10–14 kg/ha. The rate trials for the Alafua site indicated an optimum level of N approximately 300 kg/ha, K approximately 100 kg/ha, Mg > 120 kg/ha, Cu 1.5–3.0 kg/ha and Ni 0.2 kg/ha.

Table 2. Relative dry weights of plant tops from nutrient omission pot trials conducted on nine recently cleared (RC) or continuously cropped (CC) sites in Western Samoa.

Treatment	Dry weight of tops relative to 'All' treatments = 100%								
Site	1	2	3	4	5	6	7	8	9
All	100	100	100	100	100	100	100	100	100
All–N	**85	**88	**83	98	**85	92	**80	**78	92
All–P	**76	**83	**74	95	**86	91	**72	**61	**73
All–K	96	95	92	96	94	97	**81	**66	**78
All–Mg	95	97	96	104	94	96	**85	89	99
All–S	92	97	92	98	96	93	90	93	93
All–Fe	94	100	96	106	100	95	—	**72	94
All–B	97	97	101	106	98	98	99	91	98
All–Mn	98	99	92	99	96	99	87	**77	90
All–Zn	95	91	94	96	98	91	88	**79	98
All–Cu	96	90	92	96	95	96	**82	88	98
All–Mo	100	103	91	103	100	98	—	**79	98
All–Co	109	91	98	100	**85	102	92	**74	95
All–Ni	104	95	101	92	95	98	**75	89	86
All+Lime	—	—	—	104	**115	100	95	89	89

Key:
Site 1 = Laloanea CC; Site 2 = Laloanea RC; Site 3 = Tapatapao CC; Site 4 = Tapatapao RC; Site 5 = Salani CC; Site 6 = Salani RC; Site 7 = Alafua CC; Site 8 = Afiamalu CC; Site 9 = Afiamalu RC
** Significant at LSD (p=0.05)

Conclusion

The nutrient omission pot trials identified a number of nutrients that were potentially limiting in the selected sites. The fertility of RC sites was much higher than that of CC sites but two RC sites were still deficient in P and N or K. The Afiamalu CC site was the most depleted one showing deficiencies in three macronutrients (N, P and K) and five micronutrients (Fe, Zn, Mn, Mo and Co). Alafua cropped soil was deficient in four macronutrients (N, P, K and Mg) and two micronutrients (Cu and Ni).

Rate trials confirmed deficiencies identified in the omission trials and provided a rough guide to the rates of nutrient application that would be appropriate for subsequent field trials.

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References

Andrew, C.S. and Fergus, I.F. 1964. Techniques in plant nutrition and the fertility survey. In: Some Concepts and Methods in Sub-tropical Pasture Research. Commonwealth Agricultural Bureaux Bulletin, 47. 173–185.

Asher, C.J. and Grundon, N.J. 1991. Diagnosis of nutritional limitations to plant growth by nutrient omission pot trials. Department of Agriculture, The University of Queensland. 15 p.

Blackmore, L.C., Searle, P.L. and Daly, B.K. 1987. Methods for soil chemical analysis of soils. New Zealand Soil Bureau Scientific Report, 80. 103 p.

Chaminade, R. 1972. Recherches sur la fertilité et la fertilisation des sols en régions tropicales. Agron. Tropicale (France) 27. 891–904.

Chairatna, N., Nipa, P., Charassri, N., Wichai, P., Aitken, R.L., Asher, C.J. 1986. Soil fertility assessment in southern Thailand. Transactions of the Congress of the International Society of Soil Science, Hamburg, West Germany, 13–20 August 1986. 887–888.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, New York, USA. 694 p.

Sensitivity of Sweet Potato Lines to Ca and Al Stress in Solution Culture

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Abstract

An accurate estimate of total land area under acid soils in the South Pacific is difficult because of limited information on many of the soils. While acid soils may be widespread, little research has been conducted into effects of acid soil factors on the important root crops in the region. The present study was conducted to investigate the effects of low calcium (Ca) and of soluble aluminium (Al) in solution on early growth of 15 sweet potato lines. Increasing solution Ca concentration from 4 to about 400 μM improved growth of all the sweet potato lines. On the other hand, 25 to 100 μM Al in solution had an adverse effect on growth of all lines. On the basis of top and root relative dry mass, lines LO323 and L135 produced the lowest (or near lowest) yields under both Ca deficiency and Al toxicity. On the same basis, L49 and L46 were consistently the most tolerant of the two stress conditions imposed. These results suggest that the response of sweet potato lines to Ca deficiency and Al toxicity may be related.

ACID soil infertility is a major problem throughout many tropical regions (Sanchez and Logan 1992). While it is difficult to define acid soils precisely, acid soils are characterised by one or more of the following factors; low pH, high aluminium (Al) or manganese (Mn), deficiencies in phosphorus (P), calcium (Ca), magnesium (Mg) or molybdenum (Mo). An accurate estimate of total land area under acid soils in the tropics is difficult because of the diversity in chemical and physical properties among tropical acid soils (Eswaran et al. 1992), the number of soil classification systems used (Sanchez 1976; Wambeke 1992), the limited chemical data for many tropical soils, and the degree of extrapolation involved when information from smaller mapping units is extended to larger-scale maps (Wambeke 1992). Nevertheless, acid soils are abundant in the tropics. Many of these acid soils are classified under the USDA soil classification system as Oxisols and Ultisols, and combined occupy 40–60% of the total land area in the tropics (Sanchez and Logan 1992; Wambeke 1992).

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In the Pacific, limited information is available on acid soils. However, analytical data on some soils from the region indicate that acid soils may be widespread (Bleeker 1983; Naidu et al. 1991). Tropical root crops are important staples and export commodities in many South Pacific nations. The major root crops in terms of area planted and total production are sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta* and *Xanthosoma sagittifolium*), yam (*Dioscorea* spp.) and cassava (*Manihot esculenta*) (FAO 1991).

While chemical analyses of some soils from the South Pacific suggest that acid soils are widespread, little research has been conducted into effects of acid soil factors on the important root crops in the region. The objective of the present study was to investigate effects of low solution Ca and of soluble Al on early growth of sweet potato in solution culture.

Materials and Methods

Two types of solution culture techniques, still and flowing culture, were employed (Asher and Edwards 1983). Earlier studies investigating effects of solution pH on early growth of sweet potato revealed that the optimum solution pH for most cultivars was around pH 5.5 (Ila'ava et al. 1994), with good growth evident between pH 4.0 and 7.0. Based on these results, it was decided that subsequent experiments investigating effects of acid soil factors on sweet potato would be conducted using nutrient solutions at approximately pH 4.3.

Still solution culture

Two still culture experiments, to study the response of sweet potato to Ca or Al, were conducted in 22 L pots of continuously aerated nutrient solution. The experiments were arranged in a split plot design with the Ca or Al treatments as main-plots, and four cultivars, Wanmun, Lole, Hawaii and Beerwah Gold, as sub-plots. Six Ca treatments were imposed with mean concentrations during the experiment of 4, 13, 41, 144, 397 and 1328 μM Ca using a mixture of $CaCl_2$, $CaSO_4$ and $Ca(NO_3)_2$ as the Ca source. All nutrients were added in a liquid form except for $CaSO_4$, which was added as a solid. Four Al treatments, 0, 25, 50 and 100 μM Al, were studied by adding appropriate amounts of 0.25 μM $AlCl_3$ stock solution to each pot. This was done a few hours after the addition of the basal nutrients and after the pH of the nutrient solutions had been checked. In both experiments, there were six replicates.

One of two 20 cm long cuttings of each cultivar with either two or three leaves were weighed before being placed in plastic cups with holes in their base through which 25% of the basal end of the cuttings protruded. The cups were then half-filled with black polyethylene beads to hold the cuttings in place and prevent light reaching the nutrient solution.

The composition of the basal nutrient solution was (μM): 1600–1900 N; 500–1500 K; 400 Ca (except for the Ca experiment); 410 S; 400 Mg; 10 B, Fe, Cl and Na; 5 Mn; 2–3 P; 2 Zn; 2 Mo; and 1 Cu. Solution pH was adjusted daily using either 1M HCl or 1M NaOH, and samples of solution from each pot were collected daily for analysis of P, K, Ca, S, Mg, Fe, Mn, Zn, Cu, Mo and Al using inductively coupled plasma–atomic emission spectroscopy (ICP–AES). Where necessary, nutrient additions were made on the basis of these results.

The plants were grown for 10 to 14 days then harvested. During the growing period, temperature in the glasshouse ranged from 33 to 40°C. At harvest, plants were severed just above the solution, then the roots and plant tops separated, and weighed fresh and after oven drying at 70°C for 2 or 3 days.

Flowing solution culture

Vine cuttings were used from 15 cultivars, Lole, Hawaii, LO323, Beerwah Gold, Wanmun, L3, L11, L18, L46, L49, L131, L135, Markham, Meriken and NG7570. Each cutting was 10 cm long with three young leaves and with two to three nodes at the basal end. The composition of the basal nutrient solution was (μM): 145–1300 S; 300 N, 250 K; 10–160 Cl; 100 Mg; 10 Fe and Na; 3 B; 2 P; 0.25 Zn; 0.18 Mn; 0.07 Cu; and 0.02 Mo. Cultural conditions (i.e. planting, control of nutrient composition and harvesting) were similar to those used in the still culture experiments.

Effects of Ca (45, 400 and 1200 μM supplied as solid $CaSo_4$) were investigated at three solution Al concentrations (0, 25 and 50 μM supplied as $AlCl_3$). Because of equipment limitations, and based on findings from the still culture experiment, the effects of 1200 μM Ca at nil μM Al were not investigated. A completely randomised design was used consisting of eight treatments of Ca or Al, 15 cultivars and four replicates. Randomisation of the treatments was done twice, first at planting and then one week later. In the present paper, the response of 15 lines to low Ca was evaluated by comparing dry matter yield at 45 μM Ca with that at 400 μM Ca. Likewise, plant response to 25 μM Al was compared with that without added Al to evaluate the response of the 15 lines to soluble Al. In both cases, the Ca concentration was at 400 μM.

All the nutrients including Ca were added to the units and allowed to mix for one day. The pH was checked and where necessary adjusted to pH 5.0 before the Al treatments were imposed. Appropriate volumes of $AlCl_3$ solutions were added slowly to the designated units using a peristaltic pump. The concentration of monomeric Al in solution was checked twice weekly using the method described by Kerven and coworkers (1989). The pH in the solution in each unit was adjusted to 4.2 before planting and maintained constant thereafter, using either 0.25 M H_2SO_4 or 0.5 M KOH. This was achieved using the automatic pH control equipment incorporated in the units (Asher and Edwards 1983). Daily checks were also done using an independent pH meter (Picolo HI1290).

Results and Discussion

Effects of Ca and Al in still culture

In still culture, top and root growth of all four cultivars increased with increasing solution Ca concentration (Fig. 1). All cultivars achieved greater than or equal to 90% of maximum growth at a solution Ca concentration of 400 μM.

Increasing solution Al concentration from 0 to 25 μM in still culture produced a small increase in root growth in Wanmun and Beerwah Gold, little or no change in Hawaii and a large reduction in Lole (Fig. 2). A further increase in Al concentration to

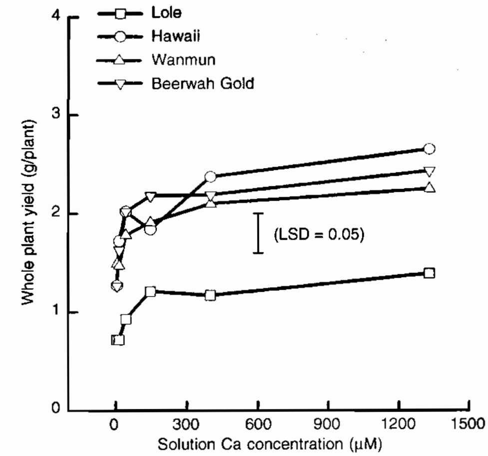

Fig. 1. Effects of solution Ca concentration on whole plant dry weight yield of sweet potato cultivars Wanmun, Lole, Hawaii and Beerwah Gold.

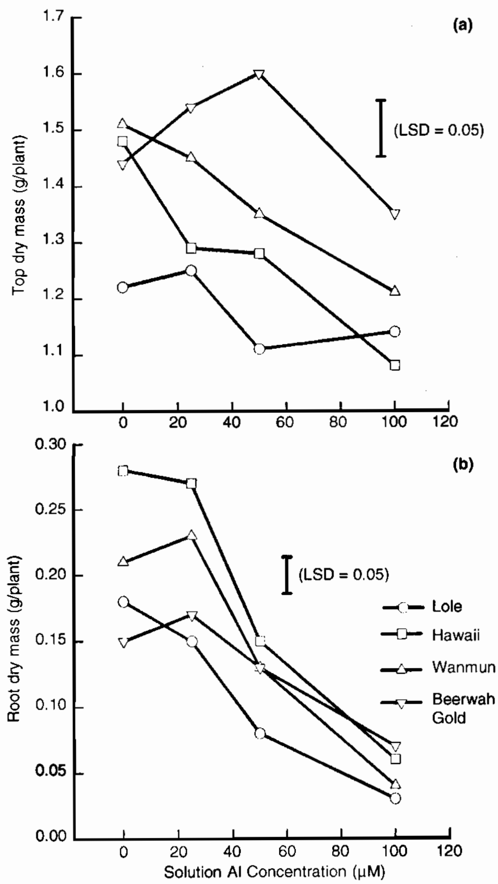

Fig. 2. Effects of solution Al concentration on (a) top and (b) root yield of sweet potato cultivars Lole, Hawaii, Beerwah Gold and Wanmun.

50 M resulted in reductions in root growth in all cultivars, and all cultivars produced their lowest root yields at 100 M Al. With top growth, Beerwah Gold recorded a significant ($P > 0.05$) increase between 0 and 50 µM Al in solution. At 100 M Al, top growth was greatly reduced. On the other hand, Wanmun and Hawaii showed a consistent linear decline in top growth between 0 and 100 µM Al. Lole also showed a reduction in top growth between 0 and 100 µM Al but the rate of decrease was not as large as that observed for Wanmun and Hawaii. Diversity in Al tolerance among sweet potato cultivars has been shown also by Munn and McCollum (1976), Sangalang and Bouwkamp (1988) and Ritchey (1991).

There is no explanation for the increase in top growth by Beerwah Gold between 0 and 50 µM Al in the present study. However, similar effects have been reported for rice (*Oryza sativa*) (Howeler and Cadavid 1976), forage legumes (Andrew et al. 1973) and maize (*Zea mays*) (Clark 1977).

Effects of Ca and Al in flowing solution culture

In the absence of added Al, all sweet potato lines other than L46 showed positive growth responses to increased Ca concentration from 45 to 400 µM in solution (data not presented). This was in keeping with the results in still culture (Fig. 1). Assuming that dry matter yields at 400 µM Ca would be the maximum possible, both top and root dry matter were reduced with 45 µM Ca in solution (Table 1). Irrespective of whether top or root yields were used, LO323 recorded the lowest relative yields while L46 produced the highest in this treatment. Overall, however, top yields were more affected by low Ca than were root yields, the relative top and root yields for LO323 being 56% and 72%, respectively. For L46, the values were 104% and 138%. Other cultivars that produced greater than 90% of their maximum top growth at 45 µM Ca in solution were L131 (93%) and L49 (95%).

Aluminium in solution at 25 µM had an adverse effect on the growth of all the sweet potato lines. Dry matter yields at 25 µM Al and 400 µM Ca were compared with zero µM Al and 400 µM Ca to determine the degree of tolerance of the 15 lines used to Al in solution. On the basis of these calculations, L135 was found to be the most sensitive line to Al in solution producing 38% and 44% of top and root dry mass, respectively (Table 1). The second most sensitive cultivar was LO323, producing 55% of top and 60% of root dry mass in the presence of 25 µM Al. On the other hand, the most tolerant cultivar, L49, produced 97% and 114% of the top and root yield at 25 µM Al. Other lines that performed well in the presence of 25 µM Al in solution were Hawaii

Table 1. Relative yield in flowing solution culture of 15 sweet potato lines at 45 μM Ca relative to 400 μM Ca, to assess the effects of low Ca; and of 25 μM Al relative to nil μM Al (both at 400 μM Ca), to assess the effects of Al in solution.

	Relative yield (%) at 45 μM Ca		Relative yield (%) at 25 μM Al	
Lines	Tops	Roots	Tops	Roots
LO3232	56 (1)*	72 (1)	55 (2)	60 (2)
L 135	68 (2)	96 (6)	38 (1)	44 (1)
Wanmun	74 (3)	90 (3)	62 (3)	75 (6)
Hawaii	78 (4)	98 (8)	85 (12)	83 (7)
NG7570	78 (4)	93 (4)	75 (9)	96 (10)
Meriken	79 (5)	97 (7)	70 (6)	74 (5)
L18	81 (6)	112 (10)	69 (5)	75 (6)
Lole	82 (7)	93 (4)	72 (8)	83 (7)
Beerwah Gold	82 (7)	88 (2)	72 (8)	70 (4)
L3	84 (8)	112 (10)	83 (11)	98 (12)
Markham	85 (9)	94 (5)	65 (4)	65 (3)
L11	87 (10)	116 (11)	71 (7)	97 (11)
L131	93 (11)	106 (9)	76 (10)	88 (8)
L49	95 (12)	130 (12)	97 (13)	114 (13)
L46	104 (13)	138 (13)	75 (9)	90 (9)

* Numbers in brackets are in order of least to highest tolerance.

(85% tops, 83% roots) and L3 (83% tops, 98% roots). As for Ca, the effect of Al in solution appeared to more pronounced on top than on root growth.

On the basis of top and root relative dry mass, LO323 and L135 produced the lowest (or near lowest) yields under both Ca deficiency and Al toxicity. Conversely, L49 and L46 were consistently the most tolerant of the two stress conditions imposed. These results suggest that the response of sweet potato lines to Ca deficiency and Al toxicity may be related.

Conclusions

The results of the present study demonstrate that there are differences in sensitivity among sweet potato lines to Ca deficiency and Al toxicity. Furthermore, the differential responses by the sweet potato lines to Ca deficiency and Al toxicity appeared to be linked. In view of these findings, future studies should be conducted further to evaluate genetic differences among sweet potato lines to Ca deficiency and Al toxicity.

References

Andrew, C.S., Johnson, A.D. and Sandland, R.L. 1973. Effect of aluminium on the growth and chemical composition of some tropical and temperate pasture legumes. Australian Journal of Agriculture Research 24. 325–339.

Asher, C.J. and Edwards, D.G. 1983. Modern solution culture techniques. In: Lauchli, A. and Bieleski, R.L., ed., Encyclopedia of Plant Physiology New Series. Inorganic Plant Nutrition. Berlin Heidelbag Germany, Springer-Verlag. 94–119.

Bleeker, P. 1983. Soils of Papua New Guinea. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian National University Press, Australia.

Clark, R.B. 1977. Effect of aluminium on growth and mineral element of Al-tolerant and Al-intolerant corn. Plant and Soil 47. 653–662.

Eswaran, H., Beinroth, F.H., Kimble, T. and Cook, T. 1992. Soil diversity in the tropics: implications for agricultural development. In: Lal, R. and Sanchez, P.A., ed., Myths and Science of Soils of the Tropics. Wisconsin USA, Soil Science Society of America Special Publication No. 29. 1–16.

FAO. 1991. Production Yearbook. Volume 45. 92–93.

Howeler, R.H. and Cadavid, L.F. 1976. Screening of rice cultivars for tolerance to Al-toxicity in nutrient solutions as compared with a field screening method. Agronomy Journal 68. 551–555.

Ila'ava, V.P., Asher, C.J. and Blamey, F.P.C. 1994. Growth of sweet potato (*Ipomoea batatas*) as affected by pH in solution culture. In: Date, R.A. et al., ed., Proceedings of the Symposium: Plant-soil Interactions at Low pH: Principles and Management. Kluwer Academic Publishers (in press).

Kerven, G.L., Edwards, D.G., Asher, C.J., Hallman, P.S. and Kokot, S. 1989. Aluminium determination in soil solution. II. Short-term colorimetric procedures for measurement of inorganic monomeric aluminium in the presence of organic acid ligands. Australian Journal of Soil Research 27. 79–90.

Munn, D.A. and McCollum, R.E. 1976. Solution culture evaluation of sweet potato cultivar tolerance to aluminium. Agronomy Journal 68. 989–991.

Naidu, R., Haynes, R.J., Gawander, J.S., Morrison, R.J. and Fitzpatrick, R.W. 1991. Chemical and mineralogical properties and soil solution composition of acid soils from the South Pacific Islands. In: Wright, R.J., Baligar, V.C. and Murrmann, R.P., ed., Plant-soil Interactions at Low pH. Netherlands, Kluwer Academic Publishers. 43–53.

Ritchey, D.A. 1991. Evaluating sweet potato tolerance to aluminium toxicity: Comparison of rapid test method and field results. In: Wright, R.J., Baligar, V.C. and Murrmann, R.P., ed., Plant-soil Interactions at Low pH. Netherlands, Kluwer Academic Publishers. 939–945.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, USA.

Sanchez, P.A. and Logan, T.J. 1992. Myths and science about the chemistry and fertility of soils in the tropics. In: Lal, R. and Sanchez, P.A. ed., Myths and Science of Soils of the Tropics. Wisconsin USA, Soil Science Society of America Special Publication No. 29. 35–46.

Sangalang, J.B. and Bouwkamp, J.C. 1988. Selection of sweet potato for tolerance to aluminium toxicity: screening procedures and field test. Journal of American Society of Horticultural Science 113. 277–281.

Wambeke, A.V. 1992. Soils of the Tropics: Properties and Appraisal. New York, McGraw-Hill Inc. 125–137.

Soil Fertility and Sweet Potato Research in Tonga — Nitrogen and Phosphorus

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Abstract

Glasshouse nutrient omission pot and nutrient rate trials with maize were conducted on 19 of the major soil types of Tonga. Subsequently, field trials to study responses of sweet potato to phosphorus (P) rates and application methods (placement and broadcast) and application of nitrogen (N) were carried out.

In the nutrient omission pot trials, all study soils were deficient in N, 16 in P, 5 in sulfur (S), 3 in potassium (K), 1 in zinc (Zn), 1 in manganese (Mn) and 1 in iron (Fe). In the glasshouse rate trials the responses to P application were rather slow with maximum yields obtained at rates of 500 kg P/ha or more, except for Nuku'alofa soil in which maximum yield was obtained with 320 kg P/ha. The responses to N applications were relatively more rapid, maximum yields attained with rates between 75 and 200 kg N/ha.

In the field trials the main effects of P and its placement applications were significant at P=0.05. The maximum vine growth and tuber yields in the broadcast treatments were attained with rates 2 to 7 times the maximum placement yield rates. The N application rates for maximum vine growth and yields were 47.5 to 600 kg N/ha.

AGRICULTURE possibly started in Tonga in the latter half of the first millennium BC (Groube 1971). With increasing population pressures over the years, shifting cultivation has evolved into more intensive fallow systems and ultimately into permanent cultivation systems, with an accompanying decline in soil fertility.

Commencing about 1975, the Soil Bureau of the New Zealand Department of Scientific and Industrial Research (DSIR) undertook a comprehensive soil survey of the Kingdom including some soil fertility assessment of major soil types on the raised coral islands. The results from glasshouse experiments employing the nutrient omission method showed that all soils were N-deficient, all except Uoleva, Vaini, Lapaha and Hango soils were P-deficient, and most topsoils in Tonga, apart from Vava'u, were poorly supplied with S (Hart, Widdowson and Fa'anunu 1981; Widdowson and Watts 1989; and Widdowson 1992). However, they thought that S is unlikely to be a problem in the field because of better supply in the subsoil and S in rainfall accession. Some evidence of micronutrient deficiency was obtained also, but the individual micronutrients could not be identified because of the use of a combined 'all micronutrients' treatment. Field trials using maize (*Zea mays*) confirmed that N and P were the main limiting nutrients throughout the Kingdom. In the early 1990s Halavatau (1990 1991) and Manu (1991) found K and S limiting in fields intensively cultivated for a few years.

The present paper reports results from greenhouse trials and preliminary results from some field trials with sweet potato (*Ipomoea batatas*) designed to: (i) identify mineral nutrient limitations to root crop production throughout the Kingdom; (ii) determine optimum fertilizer recommendations for selected combinations of crop and soil by means of greenhouse and field experiments; and (iii) select and calibrate, under local conditions, a series of laboratory soil tests that can in future be used to predict fertilizer needs without recourse to further time-consuming and costly greenhouse and field experiments.

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Materials and Methods

Site selection and soil sampling

Reconnaissance surveys identified 19 soils with fertility problems sufficiently severe to produce visible symptoms of nutrient deficiency in the field. Bulk soil samples of the top 15 cm were collected from these sites. Soils were air-dried and passed through a 4 mm plastic sieve, and placed into 15 cm diameter polyethylene lined pots holding 1.5 kg of soil. About 0.5 kg of soil from each site was taken for chemical analysis. Chemical properties for 12 of the soils are shown in Table 1.

Omission trials

Prior to the omission trials, preliminary rate trials were conducted in the greenhouse with 6 treatments (0ALL, 0.5ALL, ALL, 2ALL, 3ALL and 4ALL). The aim was to optimise the basal application of nutrients for each soil. Nineteen soils were included in the study. Omission trials for each soil were carried out following the preliminary rate trials. The treatments were: complete nutrient application (ALL), ALL minus N, ALL minus P, ALL minus K, ALL minus Ca, ALL minus Mg, ALL minus S, ALL minus Zn, ALL minus Fe, ALL minus Cu, ALL minus Mn, ALL minus Mo, ALL minus B, and ALL minus Ni. Four replications of each omission treatment and eight replications of the 'all' treatment were employed as recommended by Andrew and Fergus (1964). The pots were arranged in a randomised block design. The nutrient salts were applied to the soil and thoroughly mixed before seeding with sprouted Hycorn 90 maize seeds (imbibed in 200 µM $CaSO_4$). The pots were watered to field capacity every day on weight basis.

After four weeks, plant tops were harvested and oven dried at 75–80°C for 3 days, then weighed. Comparisons between means of omission treatments and complete nutrient treatments (ALL) were made for each soil using a 't' test.

Nutrient rate trials

For each soil, single-element rate trials for each limiting nutrient were carried out in the greenhouse. Six rates and three replications were used in a randomised block design. For each soil, a basal application was made of other elements found to be deficient in the corresponding omission trial.

Field trials

Field experiments are needed to confirm, under conditions as near as possible to practical farming conditions, any conclusions based on laboratory or greenhouse studies. At the time of preparing this paper the following sites had been planted to sweet potato: Tu'anekivale and Longomapu in Vava'u; Uoleva and Foa in Ha'apai; Kenani in 'Eua; and Fahefa, Nuku'alofa and Lapaha in Tongatapu. Of these, tuber harvest data are available for experiments on the Uoleva soil, and observations on experiments on the Nuku'alofa, Fahefa, and Longomapu soils.

The N rates were 0, 35, 70, 140, 280, 560 and 1120 kg N/ha for Nuku'alofa soils, Tu'anekivale, Longomapu, Foa, Kenani and Fahefa soils; 0, 17.5, 35, 70, 140, 280 and 560 for Uoleva soils; and 0, 50, 100, 200, 400, 800 and 1600 kg N/ha as urea for Lapaha soils. The treatments were replicated three times and arranged in a random block design.

Table 1. Concentrations of extractable nutrients in 12 soils collected from four island groups in Tonga.

Place	Soil type	H	N	Olsen P	K	Ca	Mg	Na
			(%)	(mg/kg)		(mol (+)/kg)		
Vava'u	Longomapu	7.3	0.24	4.2	0.60	7.43	17.5	3.53
	Pangaimotu	6.8	0.17	7.6	3.00	6.13	12.0	2.63
	Tu'anekivale	7.3	0.27	4.6	0.68	7.38	11.5	4.88
Ha'apai	Uoleva	7.1	0.23	18.6	0.45	7.70	69.0	4.75
	Foa	7.3	0.23	6.6	3.30	8.00	21.3	6.95
Tongatapu	Fatai	6.8	0.25	9.6	2.45	5.90	27.6	0.28
	Vaini	7.1	0.21	30.2	4.50	7.95	29.5	4.88
	Lapaha	7.6	0.27	4.2	0.85	7.50	13.3	1.18
	Nuku'alofa	7.4	0.32	11.3	0.71	1.70	fl[1]	0.53
	Fahefa	6.1	0.17	5.2	0.75	7.95	20.5	0.70
'Eua	Kenani	7.3	0.32	3.4	0.48	7.13	11.3	2.58
	Hango	6.8	0.27	4.0	0.38	7.80	15.0	0.93

[1] free lime present

The P experiments were factorial experiments with seven P rates and two methods of applications (broadcast and placed). In the placement treatment, the P fertilizer was incorporated to a depth of approximately 20 cm over an area of approximately 300 cm^2 and two sweet potato cuttings were planted within the treated area. The P rates for coral soils (e.g. Nuku'alofa) were 2, 20, 40, 80, 160, 320 and 640 kg P/ha, whereas for the remaining volcanic ash soils the rates were 5, 50, 100, 200, 400, 800 and 1600 kg P/ha as triple superphosphate.

Results

Glasshouse pot trials

Nutrient omission trials

In all soils, plants in the 'ALL' treatments were healthy in appearance throughout the trial, but clear symptoms of deficiency were evident by day 13 to 15 in one or more of omission treatments in each soil. The dry matter yields showed that all soils were deficient in N, the relative yield in the 'ALL minus N' treatments ranging from 14.2% of the control 'ALL' treatment in the Fahefa soil of Tongatapu to 64.9% in Longomapu soil of the Vava'u islands (Table 2).

Yields of plants in the 'ALL minus P' treatments were significantly lower than the 'ALL' treatments for 16 of the soils studied. The soils in which there were no P responses were Vaini soil in Tongatapu and the Tu'avao and Hihifo soils of Niuatoputapu. The relative yields in the 'ALL minus P' treatment ranged from 9.2% in the Lapaha soil of Tongatapu to 54.9% in Foa soil of the Ha'apai islands.

Five soils gave significantly lower yields for the S omission treatments, relative yields in the 'ALL minus S' treatments ranging from 16.2% in Fahefa soil of Tongatapu to 71.2% in the Tofua soil of the Ha'apai islands.

Significant responses to K were obtained in three of the study soils. Relative yields of the plants in the 'ALL minus K' treatments ranged from 43.8% in Fahefa soil to 85.7% in Sapa'ata soil of Niuafo'ou island.

The only soils showing micronutrient deficiencies were Tongamama'o soil of Niuafo'ou (Mn, 85.7%) and Falehau soil of Niuatoputapu (Zn, 41% and Fe, 81.6%).

Table 2. Relative yields of maize tops in omission treatments differing significantly from the corresponding 'all nutrients' control treatment in 18 Tongan soils ('all' treatment = 100%).

Island group/ soil series	Relative yields for limiting nutrients (%)						
	N	P	K	S	Mn	Zn	Fe
Vava'u							
Longomapu	64.9	16.8					
Pangaimotu	44.1	34.3					
Tu'anekivale	49.1	21.3					
Ha'apai							
Uoleva	49.0	21.6					
Foa	59.5	54.9					
Tofua	50.7	19.2		71.2			
Tongatapu							
Fatai	60.0	18.8					
Vaini	59.0			54.2			
Lapaha	20.1	9.2		21.2			
Nuku'alofa	42.9	34.9		33.3			
Fahefa	14.2	20.0	43.8	16.2			
'Eua							
Kenani	51.5	13.6					
Hango	42.8	13.1					
Niuafo'ou							
Sapa'ata	55.8	20.6	85.7				
Tongamama'o	64.3	18.6			85.7		
Niuatoputapu							
Hihifo	68.5						
Tu'avao	51.2			18.0			
Falehau	77.3	21.2	51.4			41.7	81.6

Nutrient rate trials

All soils found deficient in N in the omission trials were again found to be deficient in the nutrient rate trials, the relative yields in the zero treatments varying from about 33.1% in the Lapaha soil of Tongatapu to 74.8% in Pangaimotu soil of the Vava'u islands (Table 3). The maximum yields were obtained at between 50 kg N/ha for Longomapu and Nuku'alofa soils and 300 kg N/ha for Pangaimotu and Hango soils.

As in the omission trials, the dry matter yields of maize without addition of P were quite low (mostly less than 30% of maximum yield) except in Fahefa (35.4%), Nuku'alofa (45.2%) and Uoleva soil (48.1%), and Pangaimotu (77.6%). In all soils, yields increased substantially with P application. Maximum yield was reached at 320 kg P/ha in the Nuku'alofa soil and at 500 kg/ha or more in all other soils.

Field trials

The maximum vine growth for sweet potato was obtained with 136 kg N/ha for Longomapu soil, 144 kg N/ha for Nuku'alofa soil, and 600 kg N/ha for Fahefa soil (Fig. 1). The maximum tuber yield in the Uoleva soil was obtained with 47.5 kg N/ha. The vine growth or yield of the tubers for the zero treatments were 67.3% for Nuku'alofa soil, 64.7% for Fahefa soil, 37.2% for Longomapu soil and 39.3% for Uoleva soil. Hence the soils are relatively deficient in plant-available N.

In the P trials, the main effects of P application and of placement were significant at P=0.05. In all four soils, yields at the lower rates of P application were higher where the P was placed near the point of planting than when the P was broadcast (Fig. 2). In the Nuku'alofa and Longomapu soils, effects of placement were not significant at the higher rates of application, but in the other two soils, yields in the broadcast treatments were always lower than in the placement treatments. In the Nuku'alofa soil, the lowest P rate giving maximum yield was 80 kg/ha if the P was placed or 160 kg/ha if broadcast (Fig. 2), whereas in the Longomapu soil, near-maximum vine growth was reached at 100 and 400 kg/ha respectively.

Discussion

The pot trials demonstrated that all soils were deficient in N and most were deficient in P. These results are consistent with the findings of earlier studies. However, three of the soils previously reported by Widdowson (1992) to contain adequate P for plant growth, Uoleva, Lapaha, and Hango, were found to be deficient, suggesting a decline in soil fertility since the earlier studies.

Nitrogen has been reported to be the nutrient most frequently deficient in soils of the tropics (Sanchez 1976) as a result of leaching losses of N following rapid decomposition of organic matter (Tisdale et al.

Table 3. Relative yields of maize tops (%) in the zero N and zero P treatments, and the N and P rates (kg/ha) needed for maximum yield in pot experiments conducted on 12 Tongan soils.

Island group[1]/soil series	Relative yield		Rate for maximum yield	
	Zero N	Zero P	N	P
Vava'u				
Longomapu	63.2	12.7	50	1600
Pangaimotu	74.8	77.6	300	500
Tu'anekivale	56.7	9.4	125	1000
Ha'apai				
Uoleva	72.6	48.1	250	700
Foa	73.7	17.1	190	1000
Tongatapu				
Fatai	63.1	18.3	75	800
Vaini	61.2		125	
Lapaha	33.1	15.7	115	500
Nuku'alofa	45.2	43.5	50	320
Fahefa	33.9	35.4	250	800
'Eua				
Kenani	58.0	7.6	100	1000
Hango	71.1	10.9	300	650

[1] Island groups shown in bold.

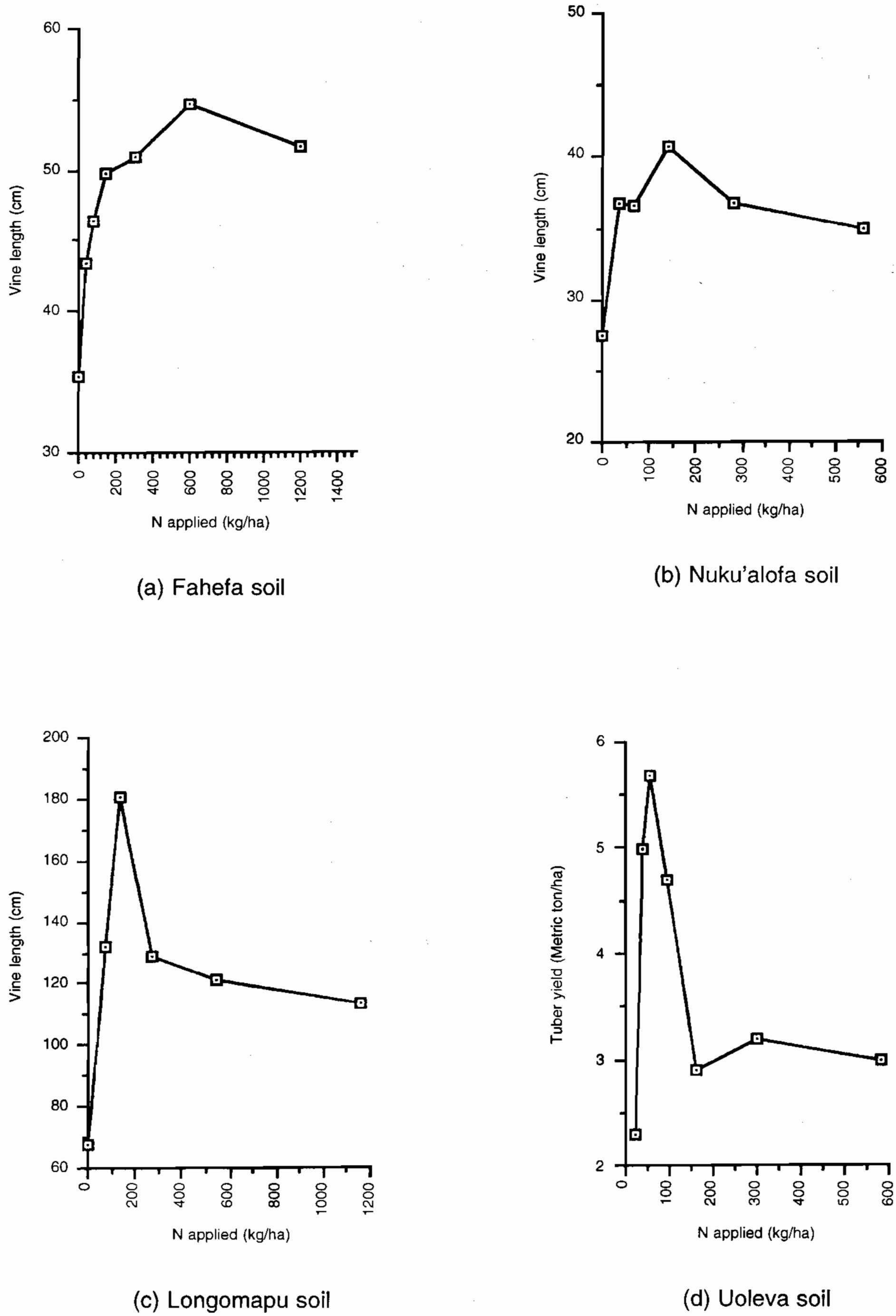

Fig. 1. Effects of N application on vine length or tuber yield of sweet potato in field experiments on four Tongan soils during the 1994–95 growing season.

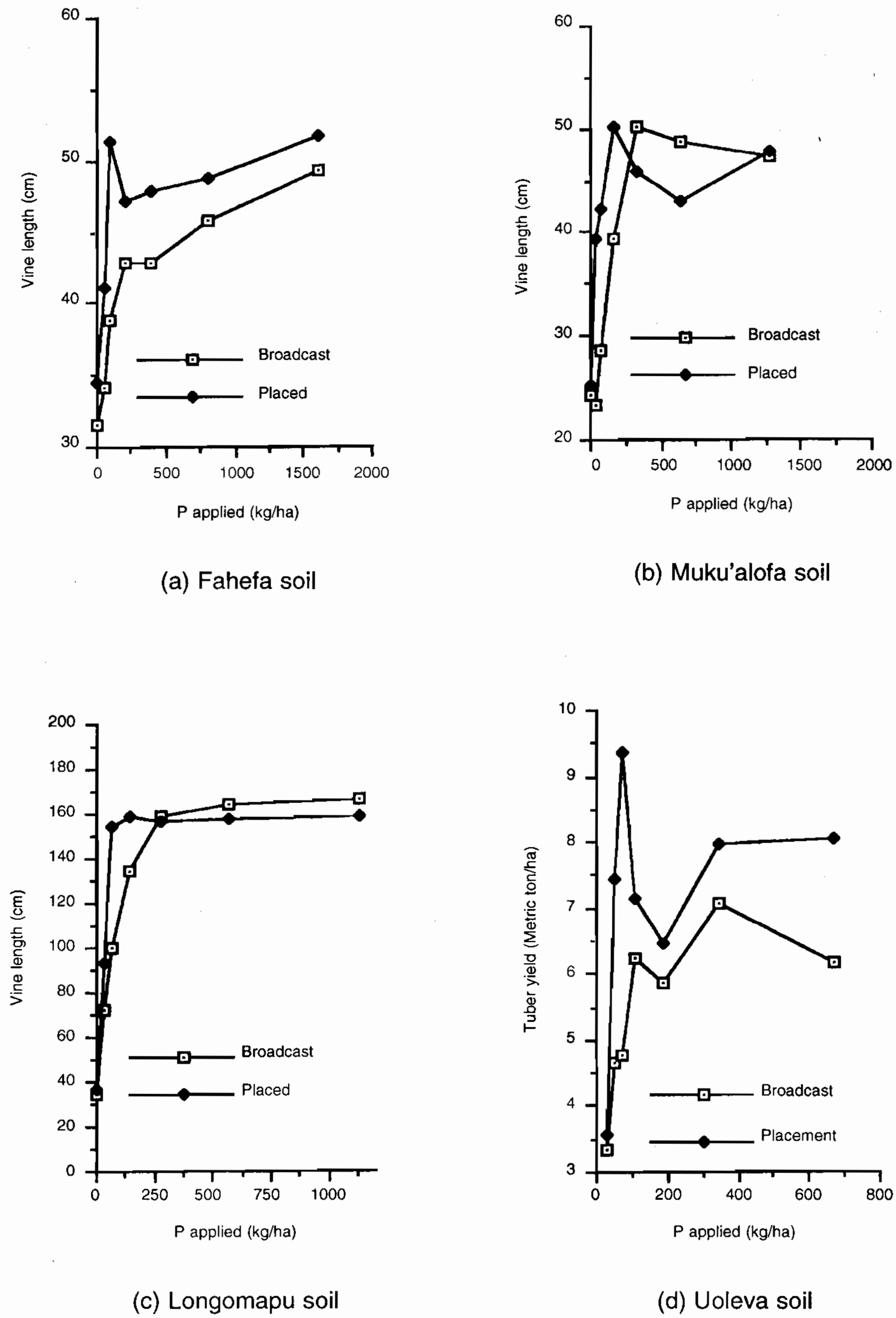

Fig. 2. Effects of P application methods on vine length or tuber yield of sweet potato in field experiments on four Tongan soils during the 1994–95 growing season.

1993). The combination of strong P fixation (Halavatau et al. 1992) and poor supply of P from parent materials (Widdowson 1992) probably explains the severe deficiencies observed in these soils in both greenhouse and field trials. Data from the limited number of field trials completed to date serve to illustrate the importance of P placement to limit P fixation losses during the life of the crop.

Several soils were found to be deficient in S. This is a surprising result given an annual rainfall accession of the order of 5 kg/ha but is in agreement with results of Widdowson (1992) who had earlier found the same soils to be S-deficient. These S-deficiencies may result from a low S content of the parent materials, and to relatively low levels of organic matter (Trangmar 1992) which are mineralised to sulfate.

Most of the soils examined appear to contain sufficient available K for the growth of crops except Fahefa, Sapa'ata, and Tu'avao soils. Widdowson (1992) reported that levels of exchangeable K declined with depth. He did not find any of the soils to be K-deficient. Reserve K (Kc) is also low in Tongan soils. This means that a K-depleted topsoil is unlikely to be replenished by a period of bush fallow.

There were only two soils deficient in micronutrients. Tongamama'o soil of Niuafo'ou was deficient in Mn and Falehau soil was deficient in both Zn and Fe. Falehau soil being a coral soil with high pH was expected to be deficient in Zn and/or Fe since the solubilities of these two nutrients decrease with increasing pH (Morrison 1988). Chemical analyses showed that Mn is low in lava rocks of Niusfo'ou (Macdonald 1948). The cultivation history of the fields may have also contributed to Mn being deficient in the Tongamama'o soil.

The nutrient omission trials were very useful in identifying the limiting nutrients in the fields, and the rate trials useful in selecting appropriate rates of applications tested in the field. The nutrient omission trials and the greenhouse rate trials together with field trials demonstrated how impoverished the study soils are with respect to plant-available N and P, and how sweet potato growth and tuber yield may be improved by application of those elements.

References

Andrew, C.S. and Fergus, I.F. 1964. Techniques in plant nutrition and the soil fertility survey. In: Some Concepts and Methods in Sub-tropical Pasture Research. Commonwealth Agricultural Bureau Bulletin, 47. 173–185.

Groube, L.M. 1971. Tonga, Lapita pottery and Polynesian origins. The Journal of Polynesian Society, 80(3). 278–316.

Halavatau, S.M. 1990. Responses of squash (*Cucurbita maxima*) to fertilizer application and vine pruning. Unpublished report, Ministry of Agriculture and Forestry, Tonga.

— 1991. Responses of squash (*Cucurbita maxima*) to applied N, P, K and S in fields intensively cultivated for a few years. Unpublished report, Ministry of Agriculture and Forestry, Tonga.

Halavatau, S.M., Manu, V.T. and Pole, F.S. 1992. Perception of soil fertility management problems facing Tonga. In: Trangmar, B. B. ed., Proceedings of the Soil Fertility and Land Evaluation Workshop. Nuku'alofa, Tonga, 3–7 February 1992.

Hart, P.B.S., Widdowson, J.P. and Fa'anunu, H.O. 1981. Fertility Evaluation of Some Soils in Vava'u, Tonga. New Zealand Soil Bureau Scientific Report 47. 30 p.

Macdonald, G.A. 1948. Notes on Niuafo'ou. American Journal of Science, 946. 65–77.

Manu, V.T. 1991. Responses of yam (*Dioscorea alata*) to N, P, K, and S fertilization. Unpublished report. Ministry of Agriculture and Forestry, Tonga.

Manu, V.T., Kipton, H., Powell, J., Banks, L., Sheat, A. and Widdowson, J.P. 1990. Accession of SO_42-Sulfur from Tongan Rainfall. Australian Journal of Soil Research, 28. 727–736.

Morrison, R.J. 1988. Chemistry, mineralogy and classification of Pacific atoll soils. In: Ashgar, M., Davidson, T.J. and Morrison, R.J. ed. Soil Taxonomy and Fertility in the South Pacific. University of the South Pacific, Apia. 283 – 295.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York.

Tisdale, S.M., Nelson, W.L., Beaton, J.D. and Havelin, J.L. 1993. Soil Fertility and Fertilizers. Fifth edn. Macmillan Publishing Company, New York.

Trangmar, B.B. 1992. Chemistry, physics and mineralogy of Tongan soils. In: Trangmar, B. B., ed. Proceedings of the Soil Fertility and Land Evaluation Workshop, 3–7 February 1992, Nuku'alofa, Tonga.

Widdowson, J.P. 1992. Soil fertility in Tonga. In: Trangmar, B. B., ed., Proceedings of the Soil Fertility and Land Evaluation Workshop, February 3–7, 1992, Nuku'alofa, Tonga.

Widdowson, J.P. and Watts, H.M. 1989. Crop responses to fertilizers on some major soils in Tonga. In: Haynes, R.J. and Naidu, R., ed., Agricultural Development in the Pacific Islands in the 90s: Proceedings of an International Conference and Workshop, Suva, Fiji, 31 March to 1 April 1989.

Mineral Depletion of a Typic Udivitrand Through Continuous Cropping with Sweet Potato

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Abstract

At Keravat, in the lowlands near Rabaul, Papua New Guinea, nutrient omission pot trials using maize (*Zea mays*) as a test plant are being conducted to compare the nutrition status of soils either left fallow or exhausted by five consecutive crops of sweet potato (*Ipomoea batatas*). Initial results on a Typic Udivitrand, based on above-ground plant weight at 35 days, indicated the exhausted soil was P-deficient while the fallowed soil had no mineral deficiencies.

Despite application of a full complement of nutrients there was a large difference in growth rates between the exhausted soil (71.09 g/pot) and fallowed soil (164.06 g/pot) suggesting that the sweet potato cropping resulted in a non-nutritional fertility reduction or that an insufficient application rate was used. Ongoing work includes testing contrasting soil type and repeating the reported pot trials to confirm results.

FOR several decades increasing population on the Gazelle Peninsula, East New Britain Province, Papua New Guinea, has forced farmers to use shorter fallows in their food cropping systems (Newton and Jamieson 1968; Bourke 1977; Cook et al. 1989; Cundall et al. 1989). This trend is continuing with an expected doubling of population in 22 years based on the growth rate between 1980 and 1990 (National Statistics Office 1982 and 1991). Fallow periods are thus expected to continue to shorten in the future.

Recent studies (Cook et al. 1989; Tyler 1993) suggest this shortening of fallows is causing soil degradation on the Gazelle Peninsula with farmers reporting yield declines due to poor soil fertility in areas of high population density. The population increases in the next 20 years are expected to cause further fertility declines. The expectation that soil degradation would be a growing problem led to the restoration in 1989 of the soil fertility and agroforestry program at Keravat. The aims of the program are to identify causes of yield decline and to find alternative food cropping systems with a greater sustainable cropping to fallow ratio, thereby increasing the carrying capacity of the land.

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Soil management studies conducted from 1954 to 1985 are reported by Newton (1960), Newton and Jamieson (1968), Bourke, (1973, 1977) and Humphrey (1991, 1992). These trials revealed that nutrient application, especially N, was an economical method of increasing sweet potato yields on soil depleted by continuous cropping. Also, green manure additions resulted in increased tuber yields compared to controls where sweet potato was cropped repeatedly. However, none of the fertilizer treatments, green manure treatments or cropping cycle combinations maintained yields or restored them to initial levels. The underlying causes of this inability were not identified.

Further identification of physical and chemical causes of yield decline could lead to cost–effective management remedies to counter this trend. To that end, a soil exhaustion trial (KSF37) was started in 1991 with the aim of evaluating the nutrition impacts of repeated crops of sweet potato, peanuts or maize on the young volcanic soils of the Gazelle Peninsula. It was felt the nutrient omission methodology (Asher and Grundon 1991), which was introduced to Keravat in 1991 by Colin Asher, would be ideal for assessing soil fertility changes on KSF37 plots. Cropping on KSF37 trial plots continued while nursery facilities were built, and in August 1994 nutrient omission trials began. This paper reports on soil fertility changes after five consecutive sweet potato croppings grown over 28 months and some initial nutrient omission pot trial results using maize as a test plant.

Materials and Methods

The gardens were located near the villages of Tavui #3, 5 km north of Rabaul in East New Britain, and in Rangulit, in the Baining Mountains about 30 km south of Rabaul. The pot trials on Rangulit have not been completed and only Tavui results are presented.

Garden elevations ranged from about 100 to 160 m a.s.l. (above sea level). Meteorological records from nearby Rabaul indicate a mean annual precipitation of 2100 mm, mean annual maximum and minimum temperatures of 31.0 and 23.3°C respectively, with minor seasonality, June to September being slightly drier than the other months (McAlpine 1983).

Soils at the site have developed in deep volcanic ash deposited during the last major eruption of the Rabaul volcano about 1400 years ago. They were previously classified as Eutrandepts and Vitrandepts by Bleeker (1983). In the newly recognised Andisol order (Soil Survey Staff 1990) they are expected to be Typic Udivitrands (unconfirmed). Gazelle Peninsula soils are generally considered of moderate to high fertility owing to their high organic matter and good physical properties. Also, the parent materials are relatively young and largely vitric (Bleeker 1983) and may be expected to replenish lost nutrients through weathering non-crystalline particles. A sandy to loamy texture results in moderate to rapid internal drainage. Despite this the low bulk density estimated at 0.7 to 0.8 g/cm^3 (unpublished data from studies at Keravat) and high porosity ensures a high water-holding capacity typical of young volcanic soils (Wada 1985).

A minor 1937 eruption added 3 to 5 cm of airfall ash to the surface (McKee et al. 1985). The effect of this ash on soil fertility has not been studied. However, the magma of the 1937 eruption was of similar geochemistry to the 1400 bp (before present) eruption and would likely have had a replenishing effect, though this may not have caused significant fertility changes.

Soils were analysed in the National Agricultural Chemistry Laboratory in Port Moresby after drying to constant weight at 70°C and sieving to <2 mm. The methods used followed procedures in Page and co-workers (1982). Soil pH was determined in a 1:5 water suspension. Exchangeable cations were leached with NH_4OAc and determined by AAS. Cation Exchange Capacity (CEC) was measured at pH 7.0 using NH_4OAc. Available P was determined by Olson's extraction followed by colorimetric titration, N by Kjeldahl digestion followed by colorimetric titration and C by the Walkley–Black method. Particle size was estimated using the hydrometer method. Field capacity was measured using the split-tube method and allowing saturated soil to drain for 24 hours followed by oven drying to constant weight at 105°C.

Five farmers at each of Tavui #3 (Gazelle Peninsula) and Rangulit (Baining Mountains) provided land for gardens. Each was asked to provide one site that had recently been cropped to exhaustion (old) and one that had recently been under fallow and was perceived to be ready for cultivation again (new). Plots were 11m × 9m and contained areas for sweet potato variety K9 (9 mounds × 5 mounds with 21 harvest mounds in 9 m × 5 m), local peanuts and local maize.

Cropping began in June 1991 and continued until October 1993. Five crops of sweet potato were grown and harvested. Vines were allowed to dry for 2–4 weeks then mixed into the soil before the next planting. Soil was sampled by augering to 15 cm prior to the first planting, after the second crop and after the fourth crop. After the last harvest sweet potato mounds were levelled and soil collected from the top 15 cm of each garden and stored in the nursery in large woven polybags.

Preliminary nutrient omission trials began in August 1994; the main trials began in January 1995. These trials used soil combined from all the Tavui 'old' sweet potato plots. The soil was air-dried and sieved to < 5 mm before 2.1 kg was weighed into plastic bags and put into 20 cm pots. The procedures of Asher and Grundon (1991) were followed through all steps from the preparation of nutrient solutions to planting of germinants. The preliminary trial indicated the All + extra P treatment provided the best growth response. Nutrients were applied at the following rates (mg/pot) in the main experiment: 182 N as NH_4NO_3, 55 P as $NaH_2PO_4.2H_2O$, 146 K as KCl, 64.2 Ca as $CaCl_2$, 54.5 Mg as $MgCl_2.6H_2O$, 45.7 S as Na_2SO_4, 10.9 Fe as sulfate free Fe-EDTA, 3.6 B as H_3BO_3, 7.3 Zn as $ZnCl_2$, 9.1 Mn as $MnCl_2.2H_2O$, 5.4 Cu as $CuCl_2.2H_2O$, 0.7 Mo as $(NH_4)_6Mo_7O_{24}.4H_2O$, 0.2 Co as $CoCl_2.6H_2O$, 0.2 Ni as $NiCl_2.6H_2O$.

In the initial trial (sweet potato soil) seeds were germinated for five days. Germinants were sorted into three size groups and one from each was planted in each pot. In the second trial (fallowed soil) seeds were sorted by weight and only medium-sized seeds were selected and germinated for three days before planting. In each case plants were allowed to grow for 35 days. Water contents were kept at field capacity. At harvest time heights were measured to

Table 1. Means of soil nutrition factors from sweet potato gardens at Tavui for three sampling dates and two ages.

	N	pH	Ca	Mg	K	Na	CEC	BS	P	C	N	C/N
1	8	6.9	11.3	2.46	1.76	0.04	17.8	86	15.2	3.29	0.28	12.0
2	8	6.6	10.8	2.00	1.13	0.08	14.9	89	16.6	2.56	0.23	10.6
3	8	6.3	12.3	2.38	0.80	0.08	14.7	99	11.9	3.11	0.26	12.4
'P'		.002	—	—	.013	—	.088	.019	—	—	—	.037
Age												
New	12	6.5	9.9	2.27	1.23	0.07	14.7	89	14.0	2.77	0.24	11.4
Old	12	6.7	13.1	2.29	1.23	0.06	16.9	94	15.0	3.20	0.27	11.9
'P'		—	—	—	—	—	—	—	—	—	—	—
Aggregate SP		5.8	15.0	2.29	0.84	0.06	16.6	100	11.9	3.25	0.25	13.0
Aggregate Fa		——— data not yet available ———										

'—' indicates 'P' value exceeds 0.150
Aggregate samples collected in Jan. 1995 from bulked material used in nutrient omission trials.

the tip of the highest extended leaf on each plant. The combined above-ground weight was measured for each pot.

Statistical analysis was performed with MINITAB (1989) software. Analysis of variance models and procedures for Dunnett's test were derived from Steel and Torrie (1980).

Results

Nutrient omission trials are ongoing and the results herein are restricted to comparing the responses of Tavui soil cropped to sweet potato or left fallow. Table 1 displays soil test values from the three field sampling dates and from the bulked material used in the nutrient omission trials. These are arranged firstly by sampling date, to show changes over time, then by garden age treatment to show differences between 'old' and 'new' gardens. Analysis of variance indicated pH and K concentration changed significantly during the cropping period. Soils are expected to be classified as Typic Udivitrands (to be confirmed), have a mollic epipedon, a bulk density between 0.6 g/cm^3 and 0.8 g/cm^3, have an air-dried field capacity of about 28% and a sandy loam texture in all horizons above 1 m depth. Table 2 displays the sweet potato marketable tuber yields from five harvests.

Table 3 presents weight data from both pot trials. The initial analysis of variance indicated there were significant weight differences among treatments (P=0.011) for sweet potato soil as well as for fallowed soil (P=0.014). Dunnett's procedure was then used to calculate required decreases in yield/plot of 15.24 g on the sweet potato soil and 25.34 g on the fallowed soil for testing the significance of weight decreases due to omitted nutrients. This revealed that the All-P treatment was significantly lower than the All treatment on sweet potato soil, and that none of the omitted nutrients resulted in significant weight decreases on the fallowed soil. Several of the omission treatments resulted in greater maize weights than the All treatment on the fallow soil. However, a two-tailed test was not used to test the significance of larger values than the All treatment.

Table 4 indicates there were no significant height differences among treatments on either of the soils tested. Both the height and weight data indicate the corn grew better on the fallowed soil (mean weight = 164.06 g/pot) than the sweet potato soil (mean weight = 71.09 g/pot); however, a statistical comparison cannot be made between the two soils because of possible differences in growing environment and planting materials.

Table 2. Tavui sweet potato yield factors for five harvests from initially new and old gardens (fresh weights).

Harvest/ age	N	Sweet potato vines	Marketable tubers	Total tubers
			t/ha	
1	8	12.0	8.1	11.7
2	8	15.3	2.7	4.5
3	8	5.2	4.3	6.8
4	8	10.4	0.8	1.4
5	8	3.3	1.8	3.2
'P'		0.005	0.009	0.004
New	20	9.7	4.0	5.9
Old	20	8.7	3.1	5.1
'P'		0.493	0.431	0.579

Table 3. Above-ground fresh plant weights (pot totals) 35 days after planting in a nutrient omission trial.

Treatment	N	Soil cropped to sweet potato	Soil left fallow
		g	g
All+P	8	73.24	148.89
All–N	4	61.67	170.44
All–P	4	52.79	139.26
All–K	4	66.83	160.65
All–Ca	—	Not tested	
All–Mg	4	73.40	171.91
All–S	4	77.85	171.76
All–Fe	4	81.45	180.77
All–B	4	73.40	171.38
All–Mn	4	73.08	165.60
All–Zn	4	65.61	159.74
All–Cu	4	75.49	179.92
All–Mo	4	68.09	170.07
All–Co	4	72.59	163.07
All–Ni	4	77.57	158.61
'P'		0.011	0.014
Critical value		58.00	123.55

Table 4. Mean plant heights (highest extended leaf) 35 days after planting in a nutrient omission trial.

Treatment	N	Soil cropped to sweet potato	Soil left fallow
		cm	cm
All+P	8	93.7	129.6
All–N	4	89.2	129.2
All–P	4	77.0	134.3
All–K	4	89.5	133.8
All–Ca	—	Not tested	
All–Mg	4	91.1	133.2
All–S	4	84.3	140.2
All–Fe	4	95.1	127.9
All–B	4	90.5	134.9
All–Mn	4	87.2	130.6
All–Zn	4	76.8	134.6
All–Cu	4	90.2	140.7
All–Mo	4	87.7	138.4
All–Co	4	90.7	129.5
All–Ni	4	92.1	137.0
'P'		0.573	0.428

Discussion

The lack of differences between the 'old' and 'new' soils in either soil test results or yield responses is puzzling. Possibly the farmers did not understand our request or they may have had their own agenda for selecting sites for us to work on. Indeed, none of the sites they chose for us appeared to have been cropped recently and perhaps the garden age treatment, which would have been poorly measured at best, should be ignored for data analysis purposes. This result highlights one of the problems when conducting on-farm research, where the investigator has little control over the choice of study site and only hearsay knowledge of its past history.

The most notable nutrient omission results are the response to P on the sweet potato soil, and the absence of other responses despite the large difference in growth between the sweet potato soil and the fallow soil. Inexperience with the method and the disruption caused by the volcanic eruption during the preliminary trial may have resulted in a poor estimate of the base nutrient levels to use in the subsequent trials. Also, the different techniques used in seed selection and germination may have contributed to some of the difference between the mean weights of the maize on the sweet potato and fallow soils. However, there remains the possibility that a non-nutrition factor such as decreased soil aggregation and increased soil strength or an unobserved pathogen such as nematodes is responsible for the growth differences.

In previous work with sweet potato on this soil Bourke (1977) reported that tuber yield response to applied N was significant and greater than to any other nutrient. The lack of a significant response to N here could have resulted from N mineralisation during the soil storage period of 15 months in the nursery prior to planting the nursery trials. Also, Bourke's results came from soils that had been exhausted for greater periods of time and hence may have been more N-depleted. Again, it is possible that the preliminary trial may have resulted in an insufficient N application rate, for the reasons discussed above.

Further work will include re-running the above trials to confirm results, using sweet potato as the test plant and repeating the procedure using the Rangulit soil which is expected to provide greater response to fertilizer as it is considered less fertile and more easily exhausted than the volcanic Tavui soil. Depending on results, rate trials will be conducted in the nursery followed by field trials.

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References

Asher, C.J. and Grundon, N.J. 1991. Diagnosis of nutritional limitations to plant growth by nutrient omission pot trials. Department of Agriculture, University of Queensland, Brisbane.

Bleeker, P. 1983. Soils of Papua New Guinea. CSIRO, Australia. Australian National University Press, Canberra, Australia. 352 p.

Bourke, R.M. 1973. A long term rotation trial in New Britain, Papua New Guinea. Proceedings Third International Symposium Tropical Root Crops. Ibadan, Nigeria. December. 1973.

— 1977. Sweet potato (*Ipomoea batatas*) fertilizer trials on the Gazelle Peninsula of New Britain: 1954–1976. PNG Agricultural Journal 28. 73–95.

Cook, K.E., Kurika, L., Ling, G., Moxon, J.E., and Nevenimo, T. 1989. A rapid rural appraisal of the cocoa and coconut based farming systems in the north east lowlands of the Gazelle Peninsula of East New Britain Province 2–14 October, 1988. Unpublished report, Department of Agriculture and Livestock. LAES, Keravat, East New Britain Province, PNG. 180 p.

Cundall, J., Cook, K., Qually, W., Ling, G., Nevenimo, T., Levett, M., Kurika, L., Latain, O., Paon, K., and Tokurewaga, M. 1989. Smallholder preferences and agroforestry potential in the north-east lowlands of the Gazelle Peninsula of East New Britain Province. Unpublished report, East New Britain Provincial Agroforestry Committee, Rabaul, PNG. 101p.

Humphrey, W.D. 1991. A review of trials to evaluate the impact of green manuring on sweet potato (*Ipomoea batatas*) on volcanic soil in the humid tropics. Department of Agriculture and Livestock, LAES, Keravat, PNG. Technical Bulletin, 6–91.

— 1992. Long term rotation and fertilizer trials with sweet potato, groundnut, sorghum, taro and maize on volcanic soil in humid tropical lowlands. Department of Agriculture and Livestock, LAES, Keravat, PNG. Technical Bulletin 9–92. 14p.

McAlpine, J.R., Keig, Gael, and Falls, R. 1983. Climate of Papua New Guinea. CSIRO and Australian National University Press. Canberra, Australia.

McKee, C.O., Johnson, R.W., Lowenstein, P.L., Riley, S.J., Blong, R.J., de Saint Ours, P. and Talai, B. 1985. Rabaul caldera, Papua New Guinea: volcanic hazards, surveillance, and eruption contingency planning. Journal of Volcanology and Geothermal Research 23. 195–237.

Minitab Inc. 1989. Minitab reference manual. Data Tech Industries, Valley Forge PA, USA. 200 p.

National Statistics Office. 1982. 1980 national population census, pre-release: summary of final figures. Port Moresby, Papua New Guinea.

— 1991. 1990 national population census, preliminary figures: census division populations. Port Moresby, Papua New Guinea.

Newton, K. 1960. Shifting cultivation and crop rotations in the tropics. PNG Agricultural Journal 13. 93–109.

Newton, K. and Jamieson, G. I. 1968. Cropping and soil fertility studies at Keravat, New Britain, 1954–1962. PNG Agricultural Journal 20. 25–51.

Page, A.L., Miller, R.H. and Keeney, D.R. 1982. Methods of Soil Analysis: Part 2 — Chemical and Microbiological Properties. Agronomy Monograph No. 9, 2nd edn. American Society of Agronomy, Inc., Madison, Wisconsin, USA. 1159 p.

Soil Survey Staff. 1990. Keys to Soil Taxonomy, 4th edn. SMSS Technical Monograph No. 6. Blacksburg, Virginia.

Steel, R.G., and Torrie, J.H. 1980. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill, New York. 623 p.

Tyler, J.M. 1993. Smallholders opinions about the management of sustainable agroforestry in the Gazelle Peninsula. MSc thesis. Department of Graduate Studies, University of Guelph. 163 p.

Wada, K. 1985. The distinctive properties of Andosols. Advances in Soil Science 2. 173–229.

The Agronomy and Mineral Nutrition of Sweet Potato (*Ipomoea batatas*) in the Highlands of Papua New Guinea

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Abstract

The object of the paper is to discuss the agronomy and mineral nutrition of sweet potato in the highlands of Papua New Guinea. It is clear that sweet potato is the most important root crop in the highlands. It is cultivated using a wide range of practices and a large number of cultivars. Results from past research indicate that response to inorganic fertilizers by sweet potato is inconsistent. However, consistent significant response to phosphorus (P) and potassium (K) was observed on volcanic ash soils (VAS). The traditional use of compost mounding in sweet potato was found superior to inorganic fertilizer in supplying a wide range and balance of nutrients which significantly increase tuber yields. It is suggested that there is a need to re-examine the effect of inorganic fertilizers on sweet potato to produce meaningful results. It is also suggested that scientific research should focus on P and K nutrition due to their importance to root crops and limitation on VAS which are widely used to grow sweet potato in the highlands.

THE highlands region of Papua New Guinea (PNG) lies in altitudes of 1000–5000 m. Most agricultural activity occurs between 1400 and 2800 m. The region comprises five provinces: Enga, Southern Highlands, Western Highlands, Simbu and Eastern Highlands.

Root crops grown in the highlands are sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), greater yam (*Discorea alata*), lesser yam, (*Discorea esculenta),* xanthosoma taro (*Xanthosoma sagittifolium*), cassava (*Manihot esculenta*), wing bean (*Psophocarpus tetragonolobus*), and potato (*Solanum tuberosum*).

Among the root crops, sweet potato is undoubtly the most important crop to the highlanders. Other root crops serve as minor or supplementary staples and are relatively less important.

Since it is the major staple to the highlanders, agricultural R&D past and present has concentrated more on sweet potato than on other root crops in the highlands. Therefore more scientific information has been published and is available on sweet potato farming systems, agronomy, mineral nutrition, varietal performance, etc. derived under highlands environmental conditions than for the other root crops. Hence, this paper aims to focus on sweet potato agronomy and mineral nutrition and will attempt to relate these issues to the diagnosis and correction of mineral disorders of the crop.

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Importance of Sweet Potato

Sweet potato is the most important crop in PNG, particularly in the highlands regions, where it is the important staple to some 1.5 million people. It is also the main fodder for pigs, the most important livestock in the highlands.

It was estimated that sweet potato production was worth PGK200 million* in PNG 10 years ago (Bourke 1985). Currently, it is increasingly a commercial crop due to high demands in such urban areas as Lae and Port Moresby.

* Approx Aud $300 million

Agronomy

Altitude and rainfall

Sweet potato is grown from sea level to the altitudinal limit of agriculture in PNG. It can grow up to 2850 m in parts of Enga and Simbu province. However, it is vulnerable to frost damage which occurs above 2300 m. Rainfall from 1500 to 5000 mm per year is best for its production.

Soils

Sweet potato can be grown in a wide range of soils from sandy loams to heavy clays and peats. Generally it prefers a loamy well-drained soil. Organic and heavy clay soils require suitable drainage, since excessive soil moisture inhibits tuber initiation and can depress yield.

Cultivation techniques

Sweet potato is grown in the highlands using a wide range of cultivation practices which are described in detail by Bourke (1985) and summarised in Table 1. The practices vary according to location and soil types and are characterised by the extent of tillage, dimension of mounds, shape of beds with and without mounds, and mound composting.

Plant population

Traditional planting densities range from 1800 to 110 000 plants/ha. Plant population is determined by cropping practice and the mounding technique. It does not have a major influence on crop yield (Bourke 1985).

Cultivars

The first sweet potato cultivars arrived in the highlands 400 years ago and there are probably 5000 cultivars at present in PNG, making it probably the site with the biggest collection of sweet potato cultivars in the world (Yen 1974).

Farmers on average maintain 33 cultivars in their gardens (Bourke 1985). Recommended cultivars for the highlands were Markham 1, Merikan, Naveto and Serenta (Akus 1982). Wanmun variety is also popular. Sweet potato varieties are continuously evaluated and promising varieties have been identified by Pacific Regional Agriculture Programme (PRAP) work on selection, trial and dissemination of sweet potato cultivars.

Time of planting

Sweet potato is quite seasonal in the highlands. Growth and production are dictated by rainfall and the availability of soil moisture. Numerous studies have confirmed this relationship in the lowlands (King 1985) and the highlands (Kanua 1990; Bourke 1991). It was observed that tuber yields are higher during the dry season and lower during the wet. Subsistence farmers grow sweet potato all year round, regardless of seasonal effects, to ensure a continuous supply of food.

Harvesting

Sweet potato takes 6–7 months to mature in the highlands and a little longer at higher altitudes (>1800 m). Traditionally, the tubers are progressively harvested — only mature large tubers are harvested, leaving smaller ones to be harvested later. This process takes another 2–3 months after the first harvest. Single harvest is also practised, particularly in commercial gardens.

Crop yields

Subsistence yields are often very low compared to commercial or experimental yields, with yields ranging 2–50 t/ha with most values between 5 and 25 t/ha (Bourke 1985). A highest experimental yield of 71.2 t/ha was recorded by Enyi (1977) in the lowlands.

Table 1. Sweet potato cultivation techniques practised in the Highlands of Papua New Guinea.

Cultivation technique	Location
1. Minimal soil tillage.	Common on fringes and forestland in the Highlands.
2. Tillage only sufficient to form mounds.	Forested areas on slopes in Eastern Highlands.
3. Complete tillage. No mounds or mounds 10 cm high.	Grassland on steep slopes in Simbu Province.
4. Complete tillage with mounds 30 cm high in long drained or square beds.	Eastern Highlands and Simbu.
5. Complete tillage. Drained beds without mounds.	Grasslands in Southern Highlands.
6. No soil tillage. No mounds. Square drained beds.	Western Highlands valleys.
7. Large composted mounds 1.5 to 5 m in diameter.	Enga, Southern Highlands and western part of Western Highlands.

Source: Bourke (1985).

Mineral Nutrition on Soil Types

Volcanic ash soils (VAS)

In most parts of the highlands, sweet potato is widely grown on VAS that occupy a total area of 25 000 km^2 (Radcliffe 1985). VAS, despite having excellent physical properties, are poor in chemical fertility, having very high phosphorus (P) retention due to high P-fixation induced by allophanic aluminium (Al) and iron (Fe) oxides, low exchangeable potassium (K) and Effective Cation Exchange Capacity (ECEC). Possible deficiencies of calcium (Ca), magnesium (Mg), boron (B), zinc (Zn) and manganese (Mn) may occur under intensive systems of agriculture (Radcliffe 1985).

Consistent responses to P and K by sweet potato have been observed on VAS in the highlands, largely due to high P fixation and low soil K.

In Nembi Plateau of Southern Highlands, lower application rates of P and K resulted in significant response to tuber yields (D'Souza and Bourke 1986a). There was no significant response to N (urea) at 150 kg/ha. However there was a small significant response to P triple superphosphate (TSP) and a large significant response to K (muriate of potash) (MOP) at 75 kg/ha. The latter increases tuber yields by 60%. Boron (Borax) at 1.5 kg/ha and minors (Mg, Fe, Zn, Mn, Cu, B, molybdenum (Mo), cobalt (Co) and sulfur (S)) at 454 kg/ha significantly increase top growth.

Consistent results were also obtained in other parts of the Southern Highlands where there were significant responses to P and K, but at higher rates, at eight sites. Sweet potato yields continue to increase at maximum application rates of 1000 kg P as TSP and 400 kg K as sulphate of potash (SOP) per hectare (Floyd et al. 1987a).

Similar findings were observed on VAS in Simbu province by Kanua (1990) using moderate rates of urea, TSP and MOP as N, P and K respectively. There was significant response to P and P × K interaction but not N. Yields continued to rise at maximum rates of 100 kg P and 150 kg K/ha but were depressed at 150 kg N/ha. Inadequate P and K have been identified as a major constraint for sweet potato production on VAS (Floyd et al. 1987a,b). Sweet potato response to inorganic fertilizer on VAS implies that significant yield response can be obtained using lower application rates and will continue at higher rates, suggesting that optimum application rates would be also higher.

Organic soils

Sweet potato is also widely grown on organic soils such as peats in the Waghi valley of Western Highlands and swampy parts of the highlands. The soil is rich in organic matter and N and has a high C to N ratio. It becomes suitable for sweet potato after excess moisture is drained. Increased levels of N after successive sweet potato cropping have been suggested to be responsible for lower yields on organic soils (Kimber 1980). Less N was available at the initial stages of cropping because of slow rates of decomposition, but increased at the later stages. This resulted in vigorous foliage growth at the expense of tuber production.

Application of inorganic fertilizers to maintain soil fertility during successive cropping proved unsuccessful. This was observed in Kuk in the Western Highlands where non-significant responses were observed using N as urea, P as TSP, K as MOP, Ca as lime and Mg as $MgS0_4$ at rates up to 40 kg N, 70 kg P, 200 kg K, 1000 kg Ca and 40 kg Mg per hectare (Byrne 1984).

At higher application rates using P (TSP), K (MOP), B (solubor) and Mg ($MgS0_4$) on the same site, a similar response was produced. There was no significant response by sweet potato to maximum application rates of 500 kg P, 250 kg K, 250 kg Mg and 250 kg B per hectare (Byrne 1984).

Mineral soils

On mineral soils in the Eastern Highlands, sweet potato responded significantly to N as urea and K as MOP, but not P as TSP. Optimum rates of N were 40–80 kg/ha. Response to K was linear and continued to increase up to 800 kg/ha due to low soil K. There was no significant response to P at a maximum application rate of 100 kg/ha (Byrne 1984).

Recommended application rate of inorganic fertilizers

Responses to inorganic fertilizers by sweet potato have been inconsistent. However, significant responses were obtained in some trials. Fertilizer requirements of sweet potato will depend on inherent soil fertility and crop yields. In poor fertility soils, e.g. VAS, higher application rates are neccessary to attain good crop yields. Bourke (1982) recommended against using mixtures such as NPK 12:12:17 because it contain nutrients such as P that are required by sweet potato in small quantities which can be supplied by the soil. He suggested a general application rate of 45 kg N plus 90 kg K/ha.

Mineral nutrition derived from organic sources

Compost

The integration of compost with sweet potato mounds is a traditional practice widely used in Enga, Southern Highlands and western parts of Western Highlands. Significant effects of compost on sweet potato have been observed on VAS in Southern Highlands by Floyd and colleagues (1987b). Sweet potato yields responded positively to maximum compost rate of 100 t/ha which was equivalent to 300 kg N, 42 kg P and 250 kg K/ha. Because of P and K limitation on VAS, it is envisaged that significant yield response can still be obtained beyond 100 t/ha of compost.

The supply of nutrients from compost improved sweet potato yields much better than the inorganic sources. There was a greater response to compost using the grass *Ischaemum polystachyum* than the inorganic N, P and K at an equivalent rate of 80 t/ha of the grass (Floyd et al. 1987b).

The positive effects of compost were attributed to its supply of a balanced range of nutrients (Table 2). Moreover, it compensated for the loss of nutrients such as K by leaching and P by fixation on VAS by slow release of nutrients from the organic matter. The amount of nutrients released from compost depends on the type of vegetation used. Ischaemum grass which is widely used in Enga and Southern Highlands provides 75 kg N, 10 kg P and 75 kg K/ha at 20 t/ha (Bourke 1982).

Table 2. Chemical analysis of Ischaemum polystachyum used as composting material on volcanic ash soil in Southern Highlands Province.

Nutrient	Unit	Soil series	Mean dry matter		
			Pangia	Kugu	Others
N	%	0.70	1.1	0.9	0.9
P	%	0.08	0.15	0.12	0.12
K	%	1.0	0.9	0.8	0.8
S	%	0.16	0.15	0.17	0.17
Ca	%	0.29	0.53	0.4	0.4
Mg	%	0.22	0.32	0.28	0.28
Na	%	0.01	0.00	0.01	0.01
Fe	ppm	160	188	109	125
Mn	ppm	357	117	88	125
Zn	ppm	51	41	49	48
Ca	ppm	5	7	6	6
B	ppm	9	6	5	6
Dry matter	%	28	27.6	28.1	28

Source: Floyd et al. (1987b).

The recommended application rate of compost is 20 to 30 t/ha but could be higher on low soil fertility soils such as VAS (Bourke 1982).

Coffee pulp

Coffee pulp is a good source of nutrients for sweet potato and has been found significantly to increase yields (Siki 1980 ; D'Souza and Bourke 1986b). It is a good source of N and K. An application rate of 15 to 30 t/ha is recommended (Bourke 1982). Higher rates could suppress yields due to excess N.

Pig manure

Pig manure has been shown to significantly increase sweet potato yields (Kimber 1973). It is readily available in the highlands, where pigs are very important. D'Souza and Bourke (1986b) also confirmed the significant effect of pig manure in the Southern Highlands in which manure at 20 t/ha significantly increased sweet potato yield. At 15 t/ha, pig dung can generate 85 kg N, 50 kg P and 60 kg K/ha. Recommended application rate is 15 t/ha; higher rates could result in excessive N which can lead to lower yields (Bourke 1982).

Combination of compost and inorganic fertilizer

Poor content of nutrients such as P in composting material can be supplemented by inorganic sources to enhance application rates and thus improve crop yields. Floyd and coworkers (1987b) observed this response with vegetables using combinations of P as TSP at rates up to 400 kg P/ha and compost 60 t/ha on VAS in the Southern Highlands.

Similar observation was made by Preston (1990) in trials at Enga using 100 kg/ha N, P and K as urea, TSP and KCl and up to 67 t/ha *Ischaemum* grass as compost. He observed significant positive response due to the main effects of compost (C), N and P and only to the second order effects of C × K interaction. The presence and absence of K with compost increase and decrease sweet potato yield respectively.

The negative and positive responses obtained from the combination of inorganic and compost fertilizers have implications for how specific nutrient deficiencies can be addressed using the combination of both nutrient sources.

Mineral deficiencies

Diagnosing mineral deficiencies in sweet potato in PNG is mainly based on relevant studies conducted in other countries e.g. Spence and Ahmad (1967). A recent study by O'Sullivan (1992) is also useful. Information derived from such studies will be useful to researchers, extension agents and farmers to identify and correct mineral deficiencies in sweet potato. Foliar nutrient deficiency symptoms of sweet potato in the field situation are often difficult to identify, due to the resemblance of some of the symptoms to the varietal features of the cultivars and other disorders.

Furthermore, the symptoms are not markedly expressed due to sweet potato not being highly sensitive to low soil fertility, a feature developed in the last 400 years when farmers continuously selected varieties to suit specific environmental conditions such as low soil fertility. As the result, most traditional sweet potato cultivars can tolerate low soil fertility such as low-P soils.

For subsistence farmers, poor soil fertility is indicated by declining crop yields. Farmers take remedial measures to restore soil fertility when successive crop yields decline. The use of inorganic fertilizers to enhance and maintain soil fertility is not a common practice among subsistence farmers in the highlands. Traditional corrective measures such as fallowing land and sweet potato–legume (e.g. peanut) rotation, which is common in Eastern and Western Highlands provinces, are often practised to restore soil fertility.

Conclusion

The following implications can be derived from issues discussed in this paper.

(1) Sweet potato is the most important root crop in the highlands of PNG. Its cultivation in the last 400 years has resulted in the crop being fine-tuned to the farmer's needs and local environmental conditions. This is reflected in the number of cultivars grown and their adaptation to a wide range of environmental conditions such as poor soil fertility.

(2) Sweet potato yield response to inorganic fertilizers has been inconsistent in the highlands. However, on volcanic ash soils, consistent responses were observed. Therefore there is a need to re-examine the effects of inorganic fertilizers. It is suggested that fresh trials must be conducted on uniform soil types and using standard cultivars to produce consistent reliable results.

(3) Lower P and K levels exist on VAS in the highlands and are a constraint to sweet potato cultivation. This suggests that sweet potato will be highly responsive to P and K on VAS, and optimum application rates would be high.

(4) The sweet potato yield responses to organic fertilizers such as compost were superior to those induced by inorganic fertilizers. This was attributed to the former having a balanced and a wide range of nutrients.

(5) Future scientific research should focus on P and K nutrition because these macronutrients are vital to root crops. Furthermore, their limitations exist on VAS, which are common sweet potato soils in the highlands.

References

Akus, W.L. 1982. Sweet potato releases from Aiyura. Harvest, 8(2). 63–66.

Bourke, R.M. 1982. Growing sweet potato for sale in the highlands. Harvest, 8(2). 47–58.

— 1985. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. Papua New Guinea Journal of Agriculture, Forestry and Fisheries, 33(3–4). 89–108.

— 1991. Stability of sweet potato supply in the Papua New Guinea highlands. Proceedings of the 2nd annual UPWARD International Conference, UPLB Philippines. 350–360.

Byrne, P. N. ed. 1984. Department of Primary Industry Crop Research Report for the period July 1969 to December 1982 for the World Bank and PNG Agricultural Support Services Project, Port Moresby, 1984.

D'Souza, E. and Bourke, R.M. 1986a. Intensification of subsistence agriculture on the Nembi Plateau, Papua New Guinea. 1. General information and inorganic fertilizer trials. Papua New Guinea Journal of Agriculture, Forestry and Fisheries, 34(1–4). 19–28.

— 1986b. Intensification of subsistence agriculture on the Nembi Plateau, Papua New Guinea. 2. Organic fertilizer trials. Papua New Guinea Journal of Agriculture, Forestry and Fisheries, 34(1–4). 29–39.

Enyi, B.A.C. 1977. Analysis of growth and tuber yield in sweet potato (*Ipomoea batatas*) cultivars. Journal of Agricultural Science Cambridge, 88. 421–430.

Floyd, C.N., D'Souza, E.J. and Lefroy, R.D.B. 1987a. Phosphate and potash fertilisation of sweet potato on volcanic ash soils in the Southern Highlands of Papua New Guinea. AFTSEMU Technical Report No. 15, Southern Highlands, Papua New Guinea.

— 1987b. Composting and crop production on volcanic ash soils in the Southern Highlands of Papua New Guinea. AFTSEMU Technical Report No. 12, Southern Highlands, Papua New Guinea.

Kanua, M.B. 1990. Farming systems research in the Highlands of Papua New Guinea: preliminary results on sweet potato research. HAES Aiyura Occasional Paper 2/90, Aiyura, Papua New Guinea.

Kimber, A.J. 1973. Wet pig dung — its effect on sweet potato yields. HAES Aiyura Technical Report, Aiyura, Papua New Guinea.

— 1980. Growing sweet potato on organic soils in the highlands. HAES Aiyura Technical Bulletin No.15, Aiyura, Papua New Guinea.

King, G.A. 1985. The effect of time of planting on yield of six varieties of sweet potato (*Ipomoea batatas*) in the Southern coastal lowlands of Papua New Guinea. Tropical Agriculture (Trinidad), 62(3). 225–228.

O'Sullivan, J. 1992. Description of some mineral deficiencies of sweet potato (*Ipomoea batatas*). Dept. of Agriculture, University of Queensland, Australia.

Preston, S.R. 1990. Investigation of compost fertilizer interactions in sweet potato grown on volcanic ash soils in the highlands of Papua New Guinea. Tropical Agriculture (Trinidad), 67(3). 239–242.

Radcliffe, J.D. 1985. The management properties of andisols in the Southern Highlands Province of Papua New Guinea. AFTSEMU Technical Report 85/7, Southern Highlands, Papua New Guinea.
Siki, B.F. 1980. Coffee pulp as manure on sweet potato. Harvest, 6(1). 1–4.
Spence, J.A. and Ahmad, N. 1967. Plant nutrient deficiencies and related tissue composition of sweet potato. Agronomy Journal, 59. 59–62.
Yen, D.E. 1974. The sweet potato and Oceania, B.P. cited in: Bourke, R.M. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. 89–108.

Effects of Nitrogen and Water Stress on Growth and Yield of Sweet Potato

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Abstract

Water stress and low soil fertility have been identified as major reasons for low tuber yield in sweet potatoes (*Ipomoea batatas*) in developing countries in the tropics. This study was designed to determine effects of N fertilizer application on water use and yield of sweet potato, and to understand physiological processes leading to the effects of water stress on yield. Two field experiments were conducted in south-east Queensland. In each experiment there was an irrigated trial and a water-stressed trial. Dry matter production and tuber yield at maturity, and radiation interception, leaf relative water content, fibrous root length and soil water content during water stress periods were determined.

Addition of nitrogen (N) at 50 kg/ha increased plant growth and tuber yield under irrigated conditions. In the water stress trials, N application increased canopy interception of solar radiation and fibrous root growth but had no effect on water uptake, dry matter production and tuber yield. A prolonged water stress period appeared to override any potentially positive effect of N application. The results also show that sweet potato in a long growing environment can recover from severe water stress which develops during early growth stages.

DECLINING soil fertility from increased pressure on land use, and hence continuous cropping instead of traditional bush fallow in developing countries, has resulted in a need to understand relationships between crop growth and nutrient supply, particularly of N, in order to increase production. In tuber crops, a major effect of low soil N availability under well-watered conditions is to decrease top growth, while tuber yield may or may not be decreased. For example, in cassava, application of N at planting had no effect on tuber yield although it enhanced leaf area and top dry matter (DM) production during early stages of growth (Tsay et al. 1989). In potato, a positive yield response to N fertilizer was attributed to increased canopy growth early in the season, which provided more assimilates for tuber growth (Payton 1990). Similarly, in sweet potato the leaf area index (LAI) of crops grown in soils high in N was over double that of low N soils (Hahn and Hozyo 1980), and application of 60 kg N/ha and 360 kg K/ha increased top but not tuber yield (Li and Yen 1988).

Water stress is also a major problem in some tropical areas where root and tuber crops are sources of staple food and are commonly grown under rainfed conditions. It has been shown that final tuber yield was affected similarly by water stress developed at different growth stages (Taufatofua 1994). While there have been studies of water stress in sweet potatoes (Ghuman and Lal 1983; Bouwkamp 1989), there appears scarce information available on the effect of N under water-limiting conditions. Therefore, two experiments were designed to elucidate N and water availability interaction in sweet potato growth and tuber yield.

Materials and Methods

Two experiments were conducted at the University of Queensland Redland Bay farm in 1990 and 1991. Site details and climatic conditions are described elsewhere (Taufatofua 1994). In each experiment there was a well-watered, irrigated (I) trial and a

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water-stressed (S) trial. In each trial there were three levels of N (0, 50 and 100 kg N/ha) fertilizer application at planting in Experiment 1, and two levels in Experiment 2 (0 and 50 kg N/ha). Treatments in each trial were randomised in each of four blocks.

Irrigation in the S trial was withheld between 28 and 84 days after planting (DAP) after which irrigation was recommenced for the rest of the growth period in Experiment 1. In Experiment 2, irrigation was withheld for three periods between 28 and 84, 91 and 147 and 154 and 210 DAP. During each stress period in both experiments, no irrigation was applied and rainfall was excluded from the plots through the use of the automatic rainout shelter.

In both experiments, a basal fertilizer application of 60 kg/ha each of P and K (P as single superphosphate and K as muriate of potash) was broadcast the day before planting. Experiments 1 and 2 were planted with the varieties LO-323 and Beerwah-gold, respectively.

Methods for measurement and statistical analysis were described elsewhere (Taufatofua 1994). Maturity was delayed in the S trial, and the final harvest was carried out at 195 DAP for both I and S trials in Experiment 1 and at 210 DAP in Experiment 2.

Total root length (TRL) was determined only in Experiment 1. Soil cores were taken at 53 DAP (25 days after the commencement of the stress period) and soon after the end of the stress period (96 DAP), to depths of 1.0 m and 1.8 m at 53 and 96 DAP, respectively.

Soil water content was measured using a neutron moisture meter in both experiments. Measurements were made frequently throughout each of the water stress periods.

Relative leaf water content (RWC) was determined five times during a day at 30 days after stress commencement (day 30) in Experiment 2. On the same day, radiation interception by canopies was determined around midday.

Results

Radiation interception at day 30 shows a large effect of water stress and N-fertilizer application (Table 1). The lower radiation interception under water-stressed condition was due to wilting which commenced about day 20, and to reduced leaf production and increased leaf death. The effect of N application on radiation interception was more noticeable in irrigated conditions than in water-stressed conditions.

The diurnal pattern of RWC at day 30 (Fig. 1) shows that in the stress trial RWC was highest early in the morning, decreasing to a minimum by early afternoon, then increasing again by late afternoon

Table 1. Radiation interception (%) of sweet potato crops with (N50) or without (N0) nitrogen fertilizer application, grown under irrigated or water-stressed conditions. Measurements were made 30 days after stress treatments were imposed in Experiment 2.

Irrigated		Stressed	
N0	N50	N0	N50
70.0	91.0	53.5	62.0

(1600 hours). In the S trial RWC of N0 was significantly higher than N50 from morning until early afternoon, with both treatments having similar RWC from mid to late afternoon. The greatest differences in RWC between I and S trials occurred in the early afternoon. In the I trial RWC of N50 was higher than N0 throughout the day, although the difference was significant only in the mid-afternoon measurement.

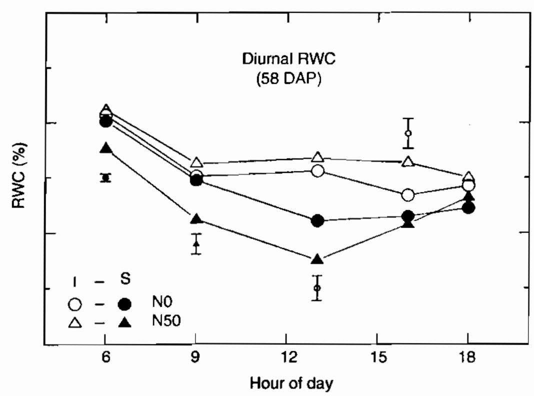

Fig. 1. Diurnal pattern of relative leaf water content of sweet potato crops with (N50) or without (N0) nitrogen fertilizer application, grown under irrigated (I) or water-stressed (S) conditions.

In Experiment 1, fibrous root length in the I trial was similar in all N levels both at 53 and 96 DAP, although N100 was slightly lower than N50 and N0 (Table 2). There was little change in TRL of the I trial between 53 and 96 DAP. At 53 DAP, 25 days after commencement of the stress period, TRL was low in the S trial, but there was a large increase in TRL thereafter, particularly in N100. In the S trial, TRL of N0 and N50 were similar but lower than in the N100 both at 53 and 96 DAP.

Change in soil water content (SWC) during the first cycle of the stress period in Experiment 2 was similar to that of the stress period in Experiment 1, when the stress period commenced on 28 DAP in both experiments (data not shown). In the first stress period SWC dropped sharply followed by a gradual decline during the last six weeks of stress. Soil water content was similar among three N treatments in Experiment 1 and between N0 and N50 throughout the three stress periods in Experiment 2. The total change in SWC in Experiment 2 was greatest and least during the first and third stress periods, respectively.

Dry matter data at harvest are shown in Table 3. In both experiments total dry matter (TDM) was increased by N application at 50 kg/ha under irrigated conditions. The effect was significant in Experiment 2. Total dry matter was not affected, however, by N treatments in water stressed conditions in both experiments. The effect of water stress was smaller in Experiment 1 than in Experiment 2, as there was a long recovery period (84–195 DAP) in Experiment 1. Top DM was generally higher under stressed conditions than in irrigated conditions, as the plants under irrigated conditions started to senesce by this time with loss of some leaves. Tuber DM yield in both experiments followed the trend of TDM: some effect of N in irrigated conditions but not in stressed conditions, and the effect of water stress was greater in Experiment 2.

Table 2. Total root length of irrigated and stressed plants at different levels of nitrogen to 1.0 m depth at 53 days after planting (DAP) and to 1.8 m depth at 96 DAP in Experiment 1.

	Total root length (km/m^2)			
	Irrigated		Stressed	
Nitrogen level	53 DAP	96 DAP	53 DAP	96 DAP
N0	12.1	16.2	2.6	10.0
N50	12.1	10.5	2.0	8.1
N100	9.2	9.1	3.6	20.6
LSD (P=0.05)	ns	ns	0.7	4.7

Discussion

Under irrigated conditions application of N increased TDM and tuber yield, but in both experiments, N0 still produced a high tuber yield, indicating that soil N level was not critically low. It appears that soil N contributed greatly to the total N uptake. Hill and colleagues (1990) reported that N uptake of 158 and 89 kg N/ha occurred with plus N and minus N treatments respectively, although only 50 kg N/ha was applied to the plus N treatment. They proposed that N-fixing bacteria and other micro-organisms have contributed to N uptake of sweet potato.

Table 3. Dry matter (g/m2) of total plants, top and tuber, and harvest index (HI) of sweet potato crops with two or three nitrogen fertilizer levels (N0, N50 and N100) grown under irrigated or stressed conditions in two experiments.

	Experiment 1							
	Irrigated				Stressed			
	Dry matter				Dry matter			
	Total	Top	Tuber	HI	Total	Top	Tuber	HI
N0	1947	456	1491	0.76	1825	522	1303	0.71
N50	2296	478	1819	0.79	1957	558	1399	0.71
N100	2331	460	1871	0.82	1833	558	1275	0.70

	Experiment 2							
	Irrigated				Stressed			
	Dry matter				Dry matter			
	Total	Top	Tuber	HI	Total	Top	Tuber	HI
N0	2060	285	1775	0.86	1358	402	956	0.70
N50	2541	360	2181	0.86	1549	439	1110	0.72

There were no visual or measured effects of water stress for approximately the first 20 days of each water stress period. Signs of stress such as leaf wilting in the early afternoons were observed when about half of the available soil water content was lost. At this stage, RWC showed marked decline and radiation interception started to decline in stressed plants. Leaf wilting also contributed to the reduction in radiation interception. Wilting was observed in the S trials after three weeks of stress.

Experiment 1 confirmed the results of other experiments which indicate the ability of sweet potato to recover rapidly from a few weeks of water stress following rewatering (Taufatofua 1994), provided a growing season is over 6 months. This was a contributing factor to the small differences (6–20%) in TDM between S and I trials at harvest. The repeated stress periods in Experiment 2 severely reduced TDM and tuber yield at harvest.

Addition of N had a positive effect in increasing root length in stressed plants. It also promoted growth during early stages as can be seen in the difference in radiation interception between different N treatments. Water extraction was not, however, affected by N application. Thus the high demand for water caused by N application appears to have had an insignificant effect on water extraction. It is possible that the small canopy in N0 resulted in increased soil evaporation (Thomas and Fukai 1995) which compensated for the small transpiration water loss. Reducing early demand for water, through reduced N application to save water for more critical stages, for example during the grain filling stage in cereals (in maize, Wolfe et al. 1988; in wheat, Syme 1972; Angus and Fischer 1991), appears to be of no benefit to sweet potato. However, it should be pointed out that the difference in radiation interception between the N treatments was rather small in the S trial of Experiment 2, and some water saving may be achieved in soils of lower N availability where canopy growth may be severely limited by N availability.

The results of radiation interception in Experiment 2 suggest that application of N had a positive effect on top growth in the early part of the stress period before severe stress developed after about day 20. However, there is an indication that increased N caused more severe water stress, and probably resulted in a reduced growth later in the stress period. It was observed that the leaves of N-added treatments tended to wilt earlier in the stress period, with RWC being lower than that of N0 in the morning. This is probably related to a higher demand for water due to higher radiation interception, whereas the soil water content pattern shows that the supply of water was the same.

There was an interaction effect of water and N on tuber yield, particularly in Experiment 2, where soil N level was probably lower than in Experiment 1 and thus there was a larger positive effect of N on TDM and tuber yield in irrigated conditions. In the S trial tuber growth was affected severely by water stress and there was no positive effect of N on tuber yield. It is concluded that N application will have little effect when water is also limiting. A prolonged water stress period appears to override any potentially positive effect of N.

References

Angus, J.F. and Fischer, R.A. 1991. Grain and protein responses to nitrogen applied to wheat growing on a red earth. Australian Journal of Agricultural Research 42. 735–746.

Bouwkamp, J.C. 1989. Differences in mid-day wilting and yield among sweet potato genotypes. Journal of the American Society for Horticultural Science 114(3). 383–386.

Ghuman, B.S. and Lal, R. 1983. Mulch and irrigation effects on plant-water relations and performance of cassava and sweet potato. Field Crops Research 7. 13–29.

Hahn, S.K. and Hozyo, Y. 1980. Sweet potato and yams. In: Symposium on Potential Productivity of Field Crops under Different Environments, IRRI, Los Baños, Laguna, Philippines.

Hill, W.A., Dodo, H., Hahn S.K., Mulongoy, K. and Adeyeye, S.O. 1990. Sweet potato root and biomass production with and without nitrogen fertilisation. Agronomy Journal 82(6). 1120–1122.

Li, L. and Yen, H.F. 1988. The effects of cultural practices on DM production and partitioning of sweet potato (*Ipomoea batatas* (L.) Lam) cultivars. Journal of Agricultural Association of China, 141. 47–61.

Payton, F.V. 1990. The effect of nitrogen fertilizer on the growth and development of the potato in the warm tropics. Dissertation Abstracts International. B, Sciences and Engineering. 50: 9. 3771B.

Syme, J.R. 1972. Features of high yielding wheat grown at two seed rates and two nitrogen levels. Australian Journal of Experimental Agriculture and Animal Husbandry, 12. 165–170.

Taufatofua, P. 1994. Agronomic manipulation of sweet potato (*Ipomoea batatas*) grown under water limiting conditions. PhD thesis, University of Queensland. 180 p.

Thomas and Fukai, S. 1995. Growth and yield response of barley and chickpea to water stress under three environments in southeast Queensland. III. Water use efficiency, transpiration efficiency and soil evaporation. Australian Journal of Agricultural Research, 46. 49–60.

Tsay, J.S., Fukai, S. and Wilson, G.L. 1989. Growth and yield of cassava as influenced by intercropped soybean and by nitrogen application. Field Crops Research, 21. 83–94.

Wolfe, D.W., Henderson, D.W., Hsiao, T.C. and Alvino, A. 1988. Interactive water and nitrogen effects on senescence of maize. I. Leaf area duration, nitrogen distribution and yield. Agronomy Journal 80. 859–864.

Some Aspects of the Mineral Nutrition of *Colocasia* sp. Taro

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Abstract

Mineral nutrition of *Colocasia* sp. taro is reviewed under the aspects of Integrated Plant Nutrition Systems (IPNS), i.e. deficiency symptoms, soil and plant analyses, pot trials, and field trials. Emphasis is given to research in Western Samoa and on coral-affected soils. Ginger is seen as a more sensitive indicator of deficiencies than other root crops.

THE edible aroids (family Araceae) include a group of 'taros'. The main 'true' taro in the South Pacific has been *Colocasia esculenta* (L.) Schott var. *esculenta* (Bradbury and Holloway 1988). Taro was more important in its Indonesian centre of diversity but has been largely displaced by rice there, while the introduction of *Phytophthora* sp. taro leaf (and corm) blight (TLB) by 1946 in Solomon Islands resulted in large-scale replacement by sweet potatoes.

Alocasia sp. giant taro is another traditional crop used in Papua New Guinea (PNG) by early settlers, and now especially in Tonga and Samoa, where its more waxy leaf is less affected by TLB. The introduction of *Xanthosoma* spp. American taro since European contact has greatly influenced the growth of *Colocasia* sp. in some areas as it is immune to TLB. *Cyrtosperma* sp. giant swamp taro is significant on atolls, and nutrient deficiency symptoms and their effects on it, including trace elements, were compared to earlier studies of *Xanthosoma*, *Colocasia*, etc. (Manuella and Cable 1992). In addition, *Amorphophallus* sp. is minor crop in the Port Moresby area of PNG.

In this paper, mineral nutrition is considered under the aspects of Integrated Plant Nutrition Systems (IPNS), i.e. deficiency symptoms, plant and soil analyses, and pot and field trials. The highly important human nutrition aspects are mentioned only briefly.

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Nutrient Deficiency Symptoms and Leaf Painting

Common symptoms on mature taro leaves of yellowing and marginal necrosis are recognised as due to deficiencies of nitrogen (N) and potassium (K), respectively. Phosphorus (P) deficiency symptom of chlorotic interveins are less commonly recognised.

Severe calcium (Ca) deficiency has been induced in taro (Sunell and Arditti 1983) in solution culture (see Pot Trials following) as did Manuella and Cable for *Cyrtosperma* sp.

Suspected K and zinc (Zn) deficiency symptoms in taro on Niue were supported by plant analysis (Lucas et al. 1977).

Xanthosoma sp. is considered a good indicator of magnesium (Mg) deficiency, and Cable (1979) noted it on an area fertilised with 2 t/ha of triple superphosphate (TSP). That area has had additional coral gravel eroded onto it and displays iron (Fe) deficiency chlorosis (Anon. 1994). Painting sections of leaf with ferrous ammonium sulphate at 2 g/L water with a few drops of Agral LN sticker gave greening within two weeks. Such symptoms with or without K or N deficiencies were seen in Tokelau also on *Alocasia* and *Cyrtosperma* sp. (Cable 1992). Application of rusty cans was tried.

Ginger, being promoted under the Australian International Development Assistance Bureau's Western Samoa Farming Systems Project in areas adjacent to some TLB trials frequently shows more severe deficiency symptoms than taro and could be a useful indicator crop.

Plant Analysis

Plant analysis of neighbouring crops or indicator plants in preliminary field uniformity or pot trials may be carried out in addition to that on taro. Magnesium deficiency symptoms were supported by reduced Mg and excess Ca concentrations in *Xanthosoma* leaves (Cable 1979). (Epsom salts corrected it.)

Dried petioles of upland taro at 3 months had 2.7% N with high fertilisation, and lowland taro 1.8% at 6 months (Manrique 1994). First-leaf P at 3 months was critical for an Hawaiian cv. at 0.41% but 0.34% for a Chinese one (Sunell and Arditti 1983). Third-leaf K at 3 months beyond 4% correlated with increased yields (Cable 1977). Free Ca was found in corms as well as leaves and discussed in relation to nutrition and acridity (Bradbury and Holloway 1988).

Partition of dry matter to corms was reduced by N fertilisation (Manrique 1994). With the application of nitrate to harvest, NO_3-N was up to 0.41% in corms and possibly anti-nutritional (Cable 1977). Critical corm P was 0.25% for a Hawaiian variety. Sodium in corms was very low, the lowest of root crops, with Zn low in parts of the PNG Highlands (Bradbury and Holloway 1988).

Soil Analysis and Sorption Studies

Soil analysis depends on correlation of results with response in the field (or pots). Organic matter, ammonium plus nitrate-N, K and cation exchange capacity on a Typic Humitropept soil in Western Samoa generally reached maxima at six weeks after mulching with *Erythrina* sp. compared to the end of the 12-week study of grass (Weeraratna and Asghar 1992).

The P sorption requirement was 0.02 mg/kg with 70% yield even at 0.003 mg/kg (Sunell and Arditti 1983). Half-maximal K uptake was found at 0.2 mM in solution (Cable 1979).

Changes were studied from unburnt fallow to two successive taro crops in five Western Samoan Tropepts (Stewart 1994). Soil water contents increased following the fallow and decreased in the second crop. Bulk density increased in the second crop of the Dystropept. In comparison with burned fallows, the flush of nutrients was small. It included increases of K on one, Ca in two, and total exchangeable bases TEB on two, and Mn and Zn on one each soil, respectively. Phosphorus decreased in two soils (one with low bulk density, Andisol). Foliar changes were also found.

A sorption study of a Typic Haplorthox (Cable 1970; Oxic Dystropept) predicted 550 kg K, 1200 kg P, 400 kg sulfur (S), 60 kg Mn, 40 kg Zn and 4 kg boron, all per hectare. Iron and copper (Cu) were high and only added in the pot trial at arbitrary levels. Harvest of the pot trial (following) found titratable acidity in the soil and reduced K, S, Mn and Zn concentrations.

Pot Trials and Solution Culture

Pot trials are often done on indicator crops such as sorghum (ratoons possible) and maize. For maize, potassium was found limiting only at two sites (Anon. 1994) and the most upland (Afiamalu) virgin area in contrast to Cable's (1977) prediction.

Some trials with taro report on deficiencies in solution cultures (Sunell and Arditti 1983). Cable (1977) grew plants upward of 10 kg each to harvest with daily KNO_3 additions to maintain K as low as 0.2 mM. Manganese, initially 0.55 mg/L was found to decrease greatly and was increased to 2.2 mg/L. Iron sequestrene initially 0.5 was reduced to 0.1 mg/L without much decrease in leaf concentration after 135 days. Water use increased to 345 L/kg fresh corm at the lowest K concentration.

A sand culture in Western Samoa was treated with 75 cm^3 of 0, 8, 16 or 32 mM NH_4NO_3-N every two days to four taro cv. including two hybrids (Jacobs and Clarke 1993). Alafua Sunrise hybrid had greater root N than the rest. Area of leaf to root, however, was least in Alafua Sunrise, as was its corm. (The latter in the field produces larger corms than cv. Niue, etc.)

A N-P-K factorial pot trial with taro in a Typic Haplustoll in Hawaii responded to N (urea) at 1 g/kg splitting N (and K) at one-third each planting (with all P), two and four months (Sunell and Arditti 1983).

Field Nutrition Trials and Disease Interaction

Traditional fertilisation of *Cyrtosperma* sp. (and taro) pits on atolls depends on composts of high humus soil with dry leaves as well as fresh of some (Manuella and Cable 1992). Sustainable use is seen as requiring fallows (generally decreasing) and manuring and/or mulching (Vargo 1993).

Yields (disappointing) were increased with up to 60 t/ha of *Erythrina* sp. mulch (Weeraratna and Asghar 1992; see also section 'Plant and Soil Analyses'). Although soil K was also increased the effect may have been more to N. Rogers (These Proceedings; Anon. 1994) reported response to 90 kgP in cultivated (and virgin) Lalanea soil, especially with 45 t/ha fresh *Erythrina* sp. mulch, but with poor taro yields.

While Solomon Islands discontinued taro mineral nutrition trials, a study was made of factorial N and K treatments on *Phytophthora* leaf spot of *Philodendron* sp foliage aroid (Harkness and Reynolds 1965). High NH_4-N (300 mg/L with 15 mg P/L) reduced spots (per 100 g leaf) and growth of philodendron. Near maximum leaf production with 120 N, 15 P, 80 K (mg/L) had relatively low (2.0–2.9 spots per 100 g) spotting. A pot trial in PNG has been conducted with seven rates of P to 160 kg/ha most with basal fertilizer and three levels of *Alomae* virus (Anon. 1994). Small statistical differences have been found. Tilialo and co-workers (these Proceedings) have discussed the relationship of nutrition and disease susceptibility. In Western Samoa a fertilizer trial on TLB, growth, yield and quality of taro is just being installed (Semisi et al., unpublished). A factorial of two each N (0 or 100 kg urea-N/ha, split at 1½ and 3 months) and (TS)P (0 or 100 kg/ha in planting holes) and four K (0, 40, 80 or 160 kg KCl-K/ha) are being applied.

Integrated Plant Nutrition Systems (IPNS)

The Bridgetown Declaration of 1992 supported IPNS. The above nutrient deficiency symptoms, plant and soil analyses, pot trials, and field fertilizer responses are usually combined in IPNS, although some steps may be short-cut.

The farmer may not know the deficiency and its correction but will usually seek the remedy of shifting to better land, if available to him. Little fertilizer has been used in Western Samoa even on vegetables and bananas, and very little on taro as it was found (N applied late) to affect taste and texture adversely. Growing areas are also often relatively remote and fertile. The publication of symptoms and its use by extension officers will allow problem correction and more intensive land use, the soil scientist or plant nutritionist integrating this information with soil and/or plant analyses to confirm suspected symptoms. In a completely integrated system this step is followed with pot trials, often with indicator crops, before agronomists conduct field trials to check predictions and economics.

References

Anonymous. 1994. Diagnosis and correction of mineral nutrient disorders of root crops in the Pacific. Australian Centre for International Agricultural Research (ACIAR) Project 9101 Annual Report 1993, 46 p.

Bradbury, J.H. and Holloway, W.H. 1988. Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific. ACIAR Monograph No. 6, 201 p.

Cable, W.J. 1977. Potassium requirement of taro in relation to growth, foliar analysis, yield and quality as grown in solution culture. In: Leakey, C.L.A., ed., Third Symposium on Tropical Root and Tuber Crops, Ibadan, Nigeria, 2–6 December 1973, 130–136.

— 1979. The fertilizer requirement of taro (*Colocasia esculenta* (L.) Schott cv. Niue) in a Typic Haplorthox soil in Western Samoa. Alafua, University of the South Pacific, School of Agriculture Miscellaneous Publication 5/79, 22 p.

— 1992. Common nutrient deficiency symptoms of crops of Tokelau and other coral soils and their correction. Journal of South Pacific Agriculture 1(2), 43–52.

Harkness, R.W. and Reynolds, J.E. 1965. Effect of nitrogen and potassium nutrition on the *Phytophthora* leaf spot of *Philodendron oxycardium*, Florida Foliage Grower 2(1), 3–5.

Jacobs, B.C. and Clarke, J. 1993. Accumulation and partitioning of dry matter and nitrogen in traditional and improved genotypes of taro (*Colocasia esculenta* (L.) Schott) under varying nitrogen supply. Field Crops Research 31, 317–328.

Lucas, R.J., Punu, B. and Cable, W.J. 1977. Aspects of taro production on the shallow calcareous soils of Niue. In: Leakey, C.L.A. ed., Third Symposium on Tropical Root and Tuber Crops, Ibadan, Nigeria, 2–6 December 1973, 369–373.

Manrique, L.A. 1994. Nitrogen requirements of taro. Journal of Plant Nutrition 17(8), 1429–1441.

Manuella, T., and Cable, W.J. 1992. Nutrient deficiency symptoms and their effects on giant swamp taro (*Cyrtosperma* sp.) seedling growth, Journal of South Pacific Agriculture 1(2), 53–59.

Stewart, D.P.C. 1994. Unburn bush fallows — a preliminary investigation of soil conditions in a bush fallow and two successive crops of taro (*Colocasia esculenta* (L.) Schott) in Western Samoa. Field Crops Research 38, 29–36.

Sunell, L.A. and Arditti, J. 1983. Physiology and phytochemistry. In: Wang, J.K. and Higa, S. ed., Taro: A review of *Colocasia esculenta* and its potentials. Honolulu, University of Hawaii Press, 34–140.

Tilialo, R., Greenough, D. and Trujillo, E. 1995. The relationship between balanced nutrition and disease susceptibility in Polynesian taro. (These Proceedings, see index.)

Vargo, A. 1993. Summary. In: Ferentinos, L. and Vargo, A. ed., Taro production systems in Micronesia, Hawaii and American Samoa. Honolulu, Research Extension Series No. 139, 1–3.

Weeraratna, C.S. and Asghar, A. 1992. Effects of grass and dadap mulches on some soil (an Inceptisol) properties and yield of taro (*Colocasia esculenta*) in Western Samoa. Tropical Agriculture (Trinidad) 69(1), 83–87.

Diagnostic Criteria for Nutrition Disorders of Taro

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Abstract

Solution culture techniques were used to induce deficiencies in taro (*Colocasia esculenta* (L.) Schott) for (N), P, K, Ca, Mg, S, Fe, B, Mn, Zn, and Cu, and toxicities of B, Mn and Zn. Initial experiments using a cultivar of C. *elsculenta antiquorum* imposed a range of nutrient supply levels so that relationships between the growth of the plant and the tissue concentration of the test nutrient in an index tissue could be estimated. From this information, critical concentrations indicative of deficiency or toxicity have been estimated. Selected treatments were applied to two cultivars of *C. esculenta esculenta* of importance in the Pacific region, namely Niue and Alafua Sunrise, to assess any differences in expression of visible symptoms. The methods and results are reported and the visible symptoms for each disorder summarised.

TARO is an important and highly valued crop in the humid tropics throughout the world, and particularly in the Pacific. Positive responses to NPK fertilizers have been frequently recorded (e.g. de la Peña and Plucknett 1967; Ashokan and Nair 1984; Mohankumar et al. 1990), and attempts have been made to relate the yield decline in successive crops to the status of these nutrients in the soil (Mohankumar and Sadanandan 1991). This attention indicates the widespread concern that taro yields are limited by poor crop nutrition. However, recognition of nutrition disorders in the field is hindered by a lack of diagnostic information on specific disorders. Studies which document the symptoms of nutrition disorders in taro are few (Cable 1971, 1977; Miyasaka and Bartholomew 1979; Austin and Constantinides 1994). Studies of related aroid crops such as tannia (*Xanthosoma sagittifolium*) (Bull 1960; Spence and Ahmad 1967) and the giant swamp taro (*Cyrtosperma* sp.) (Manuella and Cable 1990) have also contributed to the knowledge in this area. However, there remains a need for comprehensive and reliable information which can be used as a guide to diagnosis of disorders in the field. The work presented here is an attempt to address a need, by providing detailed, comparative descriptions of disorders supported by foliar analysis. Characterisation of some disorders is still in progress, but a summary of the work completed is given.

Methods

Experimental procedure was identical for that described for sweet potato elsewhere in this publication, except that taro plants were grown for eight weeks and four replicates were used in all experiments. The whole blade of the second youngest open leaf was selected as the index tissue, after a comparison of the youngest three leaf blades and their petioles.

Several cultivars of *Colocasia esculenta esculenta* of importance in the region were obtained as pathogen-tested plantlets in tissue culture from the Pacific Regional Agricultural Programme (PRAP) Tissue Culture Facility at the University of the South Pacific, Western Samoa. Multiplication of these lines to numbers adequate for experimental work was carried out over the next two years. In the meantime, a locally available cultivar of *C. esculenta antiquorum* was used. In these experiments several supply levels of the test element were applied (for deficiencies, four levels below the estimated adequate level and one above; for toxicities, three levels above the controls) to establish the relationship between plant growth and the nutrient concentration in the index tissue.

In the 1994–95 growing season, macronutrient deficiency experiments were repeated with the cultivars Niue and Alafua Sunrise, using three deficient

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levels per nutrient plus common controls. When using *C. esculenta antiquorum*, the high level of leaf guttation at night posed a potentially high risk of contamination of nutrients between treatments. Leaves could expel in excess of 30 mL of nutrient-rich guttation fluid in a night. To avoid contamination of adjacent deficient plants, care was taken to reorientate the plants so that leaf tips of plants in high-nutrient treatments did not hang over the pots of lower treatments, or to catch the fluid with paper towelling. Guttation was not a significant problem with other cultivars.

Chemical analyses were performed as described in another paper for sweet potato (O'Sullivan et al., these Proceedings). Analyses are not yet available for the experiments of the current season.

Results and Discussion

Description of visible symptoms

Growth reductions were achieved for each disorder studied except molybdenum (Mo) deficiency, and visible symptoms were developed in each case except for deficiencies of Mo and copper (Cu). Of the other disorders, symptoms of manganese (Mn) deficiency were only slight, and those of zinc (Zn) deficiency, while distinctive, were not severe. Further research on these disorders is planned. For those experiments that have been completed with *C. esculenta esculenta*, the symptoms generally agreed with those observed previously in *C. esculenta antiquorum*.

Disorders producing symptoms mainly on the older leaves

Phosphorus deficiency

Plants suffering from phosphorus (P) deficiency showed considerable growth reduction before any symptoms were visible. The first indication was a gradual paling of the leaves from youngest (dark green) to oldest (light green), although young leaves retained very dark green colour in even severely deficient plants. Red pigmentation on the petioles increased in intensity. Acute symptoms consisted of the development of necrotic lesions on the oldest leaf, but the pattern of development varied between cultivars. Necrosis arose at the leaf margin or just inside the marginal vein. Lesions spread along the margin and inwards in an irregular pattern, sometimes bounded by major veins but often cutting across them with little deflection. Water-soaked tissue could often be seen around the edge of the necrotic area, indicating the rupture of cells prior to necrosis (Fig. 1). This was most conspicuous in the early morning when humidity was still high, and could be seen most easily on the underside of the leaf. In some cultivars, including Alafua Sunrise, necrosis usually followed a general or localised yellowing of the leaf. In cv. Niue, necrosis was usually not preceded by yellowing, and often chlorophyll was still present in recently affected tissue, giving it a muddy green-grey appearance. When necrosis developed in yellow tissue it was pale, but when it encroached on green tissue, it was blotched or rimmed with dark stain.

When necrosis is preceded by yellowing, P-deficiency may be confused with N-deficiency. Distinguishing features may be the dark green colour of the youngest leaf of P-deficient plants, the more discrete necrotic lesions, and the occurrence of necrosis when yellowing is still quite localised. When necrosis is not preceded by yellowing, the symptoms may resemble potassium (K) deficiency. In this case, general pale green chlorosis of the older leaves, a less regular pattern of necrotic lesions and the presence of water-soaked tissue flanking necrotic zones may support the diagnosis of P-deficiency.

Potassium deficiency

Mild K deficiency resulted in reduced growth rates without the same degree of leaf size reduction as seen in N and P deficiencies. No general chlorosis of the leaves was observed until the onset of leaf senescence. Acute deficiency resulted in a series of necrotic lesions around the margins of the oldest leaves. Necrosis usually began as small patches just inside the marginal vein, adjacent to a major lateral vein and following the arc of secondary veins.

Lesions were usually paired either side of the major vein, and soon coalesced across it (Fig. 2). Veins near the widest point of the leaf were common initial sites, but symptoms rapidly appeared on all or most of the main vein terminae to a similar extent, producing a regular pattern of necrotic areas around the leaf margin. Necrosis tended to spread inward rather than joining around the margin. Often a number of small lesions arose in a feathered pattern either side of the vein and coalesced with the marginal lesion. Necrotic tissue was generally rimmed, blotched or uniformly colored with a dark stain.

In some cultivars, including Alafua Sunrise, the necrosis was typically surrounded by a narrow band of yellow tissue; in Niue, chlorosis was rarely seen until necrosis was well advanced. On the underside of the leaf, the minor veins in the vicinity of necrotic areas may appear black, and the lower surface of the midrib and main veins may also be blackened. In some cases, an orange-brown stain has been seen on green interveinal tissue of leaves affected by K deficiency. As the leaf approached senescence, a

Fig. 1. Phosphorus deficiency in var. antiquorum: yellow interveinal zones become water-soaked and then necrotic.

Fig. 2. Potassium deficiency in cv. Niue: darkly stained necrotic lesions near the leaf margin, adjacent to main veins.

Fig. 3. Magnesium deficiency: pale, papery necrosis of interveinal tissue and upward cupping of older leaves.

Fig. 4. Boron toxicity in var. antiquorum: necrotic spots in interveinal tissue, particularly at the leaf margin; the general leaf colour remains dark.

mottled yellowing spread across the entire blade, again following the pattern of the secondary veins, feathering from main veins.

These symptoms were seen in plants grown in solution culture, and also in soil-grown plants with an adequate supply of water. However, K deficiency in the field may exacerbate water stress, and if water supply is marginal, symptoms of water stress may be indicative of poor K nutrition. The symptoms of water stress are interveinal necrosis, centred midway between the major lateral veins, and most severe on older leaves. If expanding leaves are affected, upward cupping will result.

Magnesium deficiency

Mg deficiency caused chlorosis of oldest leaves followed by interveinal and marginal necrosis. Necrotic tissue was pale in colour, dry and papery (Fig. 3).

The margins often curled upwards, but the leaves remained turgid until almost the entire blade was necrotic. In mild cases, the young leaves appeared healthy, and necrosis on the older leaves was preceded by the development of distinct interveinal chlorosis, in which both major and secondary veins stood out in contrast to the interveinal tissue, but faded gradually into it. In more severe cases, even young leaves displayed a general chlorosis, and development of interveinal chlorosis was indistinct. Stunting was quite severe at this stage.

Boron toxicity

Small, yellow-rimmed necrotic lesions arose and coalesced in interveinal tissue, beginning near the margin midway between the main veins (Fig. 4). Necrosis spread to fill most of the interveinal tissue before the leaves senesced. In the highest B treatment, necrotic lesions began to appear at about the time leaves became fully expanded, and rapid senescence meant that plants had no more than 3 leaves at one time. Even at this level, growth rate and size of new leaves was near-normal, indicating adequate root function. However, root tips appeared curled, laterals were very short, and some necrosis of tips and lateral roots was evident.

Manganese toxicity

Older leaves developed fine dark markings reminiscent of a sooty mildew, which followed minor veins, particularly adjacent to the midrib and approximately 1 cm either side of the main veins. The markings on the upper surface were more scattered and discontinuous, but on the lower surface the association with venation was much clearer (Fig. 5). A pale necrosis developed in patches along the leaf margins, generally just to one side of a main vein rather than in the centre of interveinal zones. A diffuse interveinal chlorosis sometimes developed, and leaves senesced prematurely. In the most severe cases, necrotic lesions developed around the minor veins and spread across interveinal zones, particularly in the distal half of the blade. Root growth was severely inhibited. Main roots frequently had necrotic tips and laterals were short and curly.

Zinc toxicity

The oldest leaves developed necrotic lesions which expanded into irregularly shaped patches of brown necrosis, usually surrounded by a narrow yellow zone. The pattern of lesions was highly variable: in some cases, the leaf became peppered with small lesions in interveinal tissue, more concentrated and larger towards the centre. In others, relatively few lesions expanded and coalesced to occupy the major portion of interveinal zones (Fig. 6). In most cases of interveinal necrosis, the original lesions seemed to be centred on minor veins. However, frequently, lesions arose along the main lateral veins nearer the margin, and spread laterally. In a few cases, the necrosis was mainly marginal. Higher levels of Zn resulted in root death and completely arrested the growth of the plant.

Disorders producing symptoms on leaves of any age

Nitrogen deficiency

Nitrogen-deficient plants were stunted, with small, pale green leaves. Older leaves often developed a pale, papery necrosis around the margins, particularly towards the tip. In plants receiving a low but steady supply of N, no further symptoms were observed. When N status was allowed to decline due to exhaustion of supply, chlorosis of the oldest leaf intensified with yellowing of either the whole leaf uniformly, or spreading from a mottled pattern highlighting the pattern of secondary venation (Fig. 7). Development of yellowing was frequently greater on one side of the blade than the other, or spread from sectors nearer the tip. Following yellowing, necrosis generally spread across the leaf blade, starting along the margins or near the tip. In contrast to sulfur (S) deficiency, leaf colour before yellowing was usually even or slightly interveinal, not fading from the centre to the margins.

Sulfur deficiency

Sulfur deficiency resulted in stunting and general chlorosis of the whole plant. Laminae were often more reduced in size than petioles, giving the plants a spindly appearance. Chlorosis on the youngest

Fig. 5. Manganese toxicity in var. antiquorum: fine black markings on the lower surface of leaf veins.

Fig. 6. Zinc toxicity: spreading necrotic lesions develop on older leaves in irregular patterns, including predominantly marginal (top), an interveinal tissue away from the margins (right), or along the main veins (left).

Fig. 7. Nitrogen deficiency, of increasing intensity, resulting in general chlorosis and senescence of the oldest leaf.

Fig. 8. Sulfur deficiency in cv. Niue: chlorosis increases and becomes more interveinal from the youngest to the oldest leaf.

leaves was a uniform mid-pale green, but became increasingly interveinal as leaves aged: marginal and interveinal tissue became paler while a broad, diffuse zone around the major veins retained a darker colour; there was little or no definition of minor veins (Fig. 8). The most severely stressed plants exhibited the least interveinal pattern of chlorosis. Oldest leaves developed light-colored, papery marginal necrosis which tended to extend inward with only slight preference for interveinal zones. Complete desiccation of the blade tended to follow fairly rapidly. Also common in these plants was the development on the senescing leaf of a very distinct yellow chlorosis extending from the centre along the major veins to about half way to the margin. This zone extended several millimetres either side of the veins and was sharp-edged. It was seen only on some plants in milder treatments, but examples arose in each of the 3 cultivars studied. The main differences between S deficiency and N deficiency were that, with S deficiency, chlorosis became increasingly interveinal as leaves aged, and there was no yellow chlorosis preceding necrosis of oldest leaves.

Manganese deficiency

Severe symptoms of Mn deficiency were not obtained in this study. A growth reduction of 40% was achieved, but was associated only with a slight general chlorosis.

Disorders producing symptoms mainly on the younger leaves

Calcium deficiency

The first signs of Ca deficiency were the appearance of pale, poorly developed interveinal tissue on new leaves. The tissue was pale green to white, forming a narrow strip midway between major veins or a V tapering from the margin, and streaking into the surrounding tissue. Slower expansion of this tissue resulted in upward cupping or incomplete unrolling, or a puckered or corrugated leaf surface. Necrosis spread from the margin into the interveinal tissue, which tended to become torn (Fig. 9). The edges of the leaf sheath were frequently necrotic, and often necrotic spots could be seen on the emerging leaf within the sheath. In more advanced cases, the interveinal tissue was initially necrotic rather than white, the petiole tended to curve downward, and the new leaves were very small and shrivelled and did not uncurl or expand. Eventually the apex died. Root growth was reduced and necrosis of root tips occurred in severe cases.

Iron deficiency

Youngest leaves developed a very distinctive interveinal chlorosis. Laminae were pale green or yellow to white with green veins standing out sharply in contrast. Major and minor veins were equally pigmented, at least initially. Chlorotic blades were small and tended to curl or cup upwards. Petioles were long in proportion to blade size. In severe cases, patches of interveinal tissue became necrotic. Symptoms appeared on plants suffering only slight growth reductions, but after the onset of symptoms growth was considerably reduced. Although the first appearance of chlorosis was in the youngest leaf, after a period of time and with turnover of the older leaves, all leaves may appear similarly affected. In cases where iron deficiency has been temporary, older leaves may seem more severely affected. Main roots were thickened, with dense but short laterals clustered behind the tip.

Boron deficiency

Boron deficiency dramatically impaired the development of new leaf blades, and eventually resulted in death of the growing point. Initially new leaf blades were small and thickened, with reduced basal lobing. They may appear cupped with white and torn interveinal tissue, similar to cases of calcium deficiency except with greater reduction of blade size. In some cases the first sign was the emergence of a petiole with no blade at all, or the sudden death in the sheath of an apparently well-formed leaf blade. In such cases, the petiole would continue to emerge, and subsequent leaves, often with very small leaf blades, usually emerged before the death of the growing point. In extreme examples the leaf blade may be only 1–2 cm long. In some cases, the root system was reduced, with a brush-like profusion of laterals near the tip and a few, very short laterals higher. However, not all equally deficient plants displayed such pronounced changes in root habit.

Zinc deficiency

Symptoms became evident only in the final 2–3 weeks of the experiment, and while the extent of growth limitation at this time was considerable, the impact on growth measured over the whole experiment was relatively small. Symptoms appeared on new leaf blades and generally consisted of pale chlorosis in interveinal tissue particularly near the midrib. Chlorosis was diffuse at the edges and usually irregular and streaky, following the lines of minor veins. Leaf expansion was inhibited, and blades were slightly cupped with margins curled inward, and often had a corrugated surface as interveinal tissue expanded less than that adjacent to

Fig. 9. Calcium deficiency in cv. Niue: pale, poorly developed tissue in interveinal zones of new leaves causing crinkling and tearing of the leaf blade as it expands.

Fig. 10. Zinc deficiency: light green chlorosis appears on young leaves, in interveinal tissue near the centre of the leaf, and becomes necrotic in severe cases.

veins. Petiole length was also reduced so affected leaves were shorter than preceding leaves. An earlier study achieved a greater intensity of zinc deficiency after three generations of transplanting of taro grown in solution culture (Edwards, unpublished). In these plants, necrosis developed in the interveinal tissue immediately adjacent to the midrib (Fig. 10). While the current experiment induced a relatively mild disorder, the symptoms obtained were consistent with the patterns of chlorosis obtained by Edwards.

Critical Tissue Concentrations

The tissue selected as an index tissue for taro was the second-youngest open leaf blade. This often corresponded to the youngest fully expanded blade (YFEB, being defined as the larger of leaves 1 and 2) depending on the stage of development of the youngest leaf at the time of harvest. The results did not differ greatly from those plotted for the YFEB, and were less variable than those for the youngest or the third leaf. The second open leaf was selected in preference to the YFEB as it is easier to identify in the field.

Table 1. Tentative critical concentrations and adequate concentration ranges in the second emerged leaf blade of taro, for a number of nutrition disorders.

Disorder	Critical concentration	Adequate range
Deficiency of:		
N (%)	3.7[a]	3.9–5.0
P (%)	0.33[c]	0.5–0.9
K (%)	4.60[b]	5.0–6.0
Ca (%)	2.0[a]	2.6–4.0
Mg (%)	0.15[a]	0.17–0.25
S (%)	0.26[b]	0.27–0.33
Fe (mg/kg)	56[a]	68–130
B (mg/kg)	23[a]	26–200
Mn (mg/kg)	21[a]	26–500
Zn (mg/kg)	22[c]	22–50
Cu (mg/kg)	3.8[a]	5.8–35
Toxicity of:		
Mn (mg/kg)	1133[c]	26–500
Zn (mg/kg)	400[c]	22–250

[a]Estimation by exponential model, [b]by regression analysis, [c]by the broken stick model

Relationships between whole plant dry matter yield and the concentration of the test element in the index tissue were plotted for each disorder studied. Typical relationships showed a decreasing slope over the deficient range, reaching a plateau in the range of sufficient to surplus supply. In such cases, exponential curves were fitted, and the critical concentration was taken as that corresponding with the 90% yield point on the curve. In other cases, when the response was approximately linear over the suboptimal range, or when the spread of data did not allow a confident curve fit, a discontinuous linear function, or 'broken stick' model was applied, in which the critical concentration was indicated at the intersection of the two linear functions. In a few cases, luxury consumption did not occur within the range of sufficient to surplus supply. Hence the relationship showed no plateau as the nutrient concentration in the index tissue did not increase with increasing supply, after maxium yield was reached. In such cases, the critical concentration was again set at the 90% yield point, taking 100% as the empirical yield maximum, as the curves fitted had no asymptote. These procedures are illustrated with respect to sweet potato elsewhere in these Proceedings. Tentative critical nutrient concentrations for each disorder are listed in Table 1.

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References

Ashokan, P.K. and Nair, V. 1984. Response of taro (*Colocasia esculenta* (L.) Schott) to nitrogen and potassium. Journal of Root Crops, 10. 59–63.

Austin, M.T. and Constantinides, M. 1994. Effects of magnesium on early taro growth. Communications in Soil Science and Plant Analysis, 25. 2159–2169.

Bull, R.A. 1960. Macronutrient deficiency symptoms in the cocoyam. Journal West African Oil Palm Research, 3. 181–186.

Cable, W.J. 1971. Results of some taro (*Colocasia esculenta* (L.) Schott) trials. South Pacific Regional Colloquium on Tropical Agriculture (SPRCTA) Research Paper Series No. 9. 37 pp.

— 1977. Potassium requirement of taro in relationship to growth, foliar analysis, yield and quality as grown in solution culture. Proceedings of the Third Symposium of the International Society for Tropical Root Crops, Ibadan, Nigeria. 103–137.

de la Peña, R.S. and Plucknett, D.L. 1967. The response of taro (*Colocasia esculenta*) to N, P, and K fertilisation under upland and lowland conditions in Hawaii. Proceedings of the International Symposium on Tropical Root Crops, Trinidad 1967, Vol. 1, II. 70–85.

Manuella, T. and Cable, W.J. 1990. Nutrient deficiency symptoms and their effects on giant swamp taro (*Cyrtosperma* sp.) seedling growth. Proceedings of the Agricultural Development in the Atolls Conference, Fiji, 1990.

Miyasaka, S.C. and Bartholomew, D.P. 1979. Calcium nutrition of taro (*Colocasia esculenta*). Proceedings of the Fifth Symposium of the International Society for Tropical Root Crops, Philippines. 665–669.

Mohankumar, C.R. and Sadanandan, N. 1991. Changes in the NPK status of the soils as affected by continuous cropping and levels of NPK application on taro in Ultisols. Journal of Root Crops, 17. 71–74.

Mohankumar, C.R., Sadanandan, N. and Saraswathy, P. 1990. Effects of levels of NPK and time application of N and K on yield of taro (*Colocasia esculenta* (L.) Schott). Journal of Root Crops, 16. 33–38.

Spence, J.A. and Ahmad, N. 1967. Plant nutrient deficiencies and related tissue composition of tannia (*Xanthosoma sagittifolium*). Proceedings of the International Symposium on Tropical Root Crops, Trinidad 1967, Volume 1, II. 61–69.

Correction of Nutrition Disorders of Sweet Potato and Taro: Fertilizers and Soil Amendments

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Abstract

Little information is available on appropriate fertilizer application for many crops of lesser importance on a world scale, in spite of their value in local communities. Also, the extent and severity of nutrition disorders is not known with any confidence. Until more information is available, the nutrition requirements of tropical root crops, including sweet potato (*Ipomoea batatas* (L.) Lam.) and taro (*Colocasia esculenta* (L.) Schott), can be estimated on the basis of nutrient removal by harvested tubers and corms. Additional information may be gained from the response of other crops to fertilizers. Nutrient removal in excess of soil reserves will inevitably result in land degradation through nutrient decline in either subsistence or commercial agriculture. Fertilizer rates, especially of nitrogen (N), phosphorus (P) and potassium (K), are available primarily for the latter system. Before more accurate recommendations can be made for sweet potato and taro, however, accurate diagnosis and knowledge of the extent and severity of nutrition disorders are required.

REDUCED plant production results from many limitations (e.g. shallow soil, drought, sodicity). These are often not amenable to correction within the socio-economic constraints of many farmers. Nutrient disorders, however, can be overcome in many instances, both from technological and economic points of view, particularly those disorders caused by deficiency of a particular nutrient.

The first step in overcoming nutrient limitations is the correct diagnosis of the particular disorder. As discussed elsewhere in this publication, a concerted effort to identify and correct nutrition disorders of tropical root crops, other than potato (*Solanum tuberosum* L.), has occurred only recently. As for other crops, correct identification of nutrition disorders may be based on visible symptoms, tissue analysis or soil analysis.

Little information is available on the diagnosis and correction of nutrient disorders of many crops of less importance on a world scale, than their importance in regions such as the Pacific. This applies to sweet potato (*Ipomoea batatas* (L.) Lam.) and taro (*Colocasia esculenta* (L.) Schott), and was a major motivation for the research conducted in ACIAR Project 9101, 'Diagnosis and correction of mineral nutrient disorders of root crops in the Pacific'.

The problem of correct application of fertilizer or amendment does not stop with correct diagnosis, since consideration of environmental conditions (both atmospheric and soil) and yield potential markedly influence the appropriate fertilizer rate. In the case of crops grown under subsistence or semi-subsistence conditions, there is the additional consideration of low availability of cash for fertilizers and limited labour for composting organic matter (Floyd et al. 1988). Furthermore, environmental considerations (often ignored for too long in mechanised agriculture) may impose severe limitations on the use of fertilizers (e.g. in atoll agriculture where the leaching of nutrients into groundwater would have dire consequences). Continued removal of nutrients in crop products, however, will inevitably result in land degradation through nutrient decline (possibly of only one nutrient in shortest supply). In this case, restoration of fertility may be economically feasible, even for farmers with limited financial reserves, provided fertilizer application is based on accurate diagnosis. Furthermore, addition of the one nutrient in shortest supply may reduce the need to clear sites of

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higher fertility. The aim of this study is the presentation of information on nutrient removal by sweet potato and taro, and an assessment of possible corrective measures for sustainable yield of these crops.

Nutrient Removal by Sweet Potato and Taro

To prevent degradation in the long term, it is necessary to ensure a positive nutrient balance in the landscape. In undisturbed environments, nutrient inputs arise from the soil itself, through weathering, which is often slow, from the atmosphere (although these inputs are often small), and from N-fixation by free-living and symbiotic organisms. With human intervention, additional inputs come from the application of fertilizers, composts and manures. Losses from a system arise through nutrient removal in harvested products and through such processes as volatilisation, runoff, leaching, fixation, and denitrification.

The determination of appropriate fertilizer applications for crops of lesser importance worldwide is difficult because of the relatively little research conducted. To overcome this problem, fertilizer rates may be estimated on the basis of nutrient removal by crops. Nutrient removal is dependent both on the concentrations of nutrients in the harvested product and on the yield obtained.

Bradbury and Holloway (1988) summarised data available on nutrient concentrations in sweet potato tubers and taro corms (Tables 1 and 2). In many instances, there is wide variation in nutrient concentrations in apparently healthy crops. Adding to the difficulty of estimating the removal of nutrients is the wide variation in yield. For example, average sweet potato tuber yield in the Pacific is approximately 12 t/ha (Table 1). In taro, the range is 14–280 kg N/ha. Considerable K would also be removed by sweet potato tubers (up to 360 kg/ha) and taro corms (up to 345 kg/ha). Because of lower concentrations of P in harvested material, its removal would be considerably less; however, there is limited availability of P in many tropical soils. Removal of other macronutrients, calcium (Ca), magnesium (Mg) and sulfur (S) and of the micronutrients would also be relatively small.

Added to the nutrients present in the tubers or corms of these crops, and removed from the field, the soil must supply essential nutrients for the growth of plant tops even though these materials may be returned to the land after harvest. Estimation of nutrients in the tops may be made using the nutrient concentrations of sweet potato vines and taro leaves and harvest index (HI) as the basis for estimating total nutrient content for a particular tuber or corm yield. The HI of sweet potato was found to range 58–88% in a number of lines (Enyi 1977), though a considerably lower value of 32% has been reported (Yoshida et al. 1970). The HI of taro is about 60%, though this would vary with cultivar and with time of harvest (P. Sivan, pers. comm.). Nutrient concentrations in plant tops may be estimated from the data presented by Bradbury and Holloway (1988).

Table 1. Range in chemical composition of sweet potato tubers (after Bradbury and Holloway 1988), and the ranges in nutrient removal by a crop of 12 t/ha (average yield of sweet potato in the Pacific) and of 100 t/ha (estimated yield potential). Nutrient concentrations on a dry matter basis were calculated using 75% moisture in the tubers.

Nutrient	Concentration (dry matter basis)	Nutrient removal (kg/ha) with tuber yield of: 12 t/ha	100 t/ha
N (%)	0.64–0.92	19–28	160–230
P (%)	0.12–0.20	3.7–6.1	31–51
K (%)	1.04–1.44	31–43	260–360
Ca (%)	0.08–0.12	2.5–3.6	21–30
Mg (%)	0.05–0.11	1.4–3.2	12–27
S (%)	0.05–0.06	1.6–1.9	13–16
Fe (mg/kg)	16–44	0.05–0.13	0.4–1.1
Mn (mg/kg)	4–10	0.013–0.030	0.11–0.25
Cu (mg/kg)	6–7	0.018–0.020	0.15–0.17
Zn (mg/kg)	8–24	0.025–0.071	0.21–0.59
B (mg/kg)	4	0.012	0.10

Table 2. Range in chemical composition of taro corms (after Bradbury and Holloway 1988), and the ranges in nutrient removal by a crop of 8 t/ha (average yield of taro in the Pacific) and of 65 t/ha (estimated yield potential). Nutrient concentrations on a dry matter basis were calculated using 70% moisture in the corms.

Nutrient	Concentration (dry matter basis)	Nutrient removal (kg/ha) with corm yield of: 8 t/ha	65 t/ha
N (%)	0.60–1.43	14–34	117–280
P (%)	0.17–0.47	4.0–11.2	39–91
K (%)	1.08–1.77	25–42	210–345
Ca (%)	0.04–0.13	1.0–3.0	8.5–24.7
Mg (%)	0.07–0.38	1.6–9.2	13–75
S (%)	0.03	0.68	5.5
Fe (mg/kg)	16–57	0.038–0.14	0.31–1.11
Mn (mg/kg)	11–16	0.027–0.038	0.22–0.31
Cu (mg/kg)	7–9	0.016–0.019	0.13–0.16
Zn (mg/kg)	40–120	0.096–0.29	0.78–2.34
B (mg/kg)	3.0	0.007	0.06

In all cases, however, the soil must supply the essential nutrients if yields are not to be reduced because of continued removal of nutrients without replacement. Indeed, decline in soil fertility has been a major cause of abandoning cleared land, allowing it to revert to natural vegetation, and the clearing of new land.

Fertilizer Application

In theory, the quantity of fertilizer (or nutrient in an organic amendment) required is the difference between the nutrient requirement of a crop and that which can be supplied by the soil plus any loss (e.g. through leaching). In practice, it is difficult, if not impossible, to provide a recipe that will cover all situations involving differences in yield potential and in soil fertility. Added to this are the different socioeconomic conditions affecting farmers around the world.

Most published research has focused on the application of macronutrient fertilizers, especially N, P and K. This is understandable, given the importance of these nutrients in crop production. However, failure to recognise deficiencies of other essential nutrients (or, indeed, other environmental limitations such as water stress and disease) in such studies may seriously affect the value of the results.

De Geus (1967) based fertilizer recommendations for sweet potato on a number of studies, suggesting rates of 50–60 kg N/ha, 18–22 kg P/ha and 65–100 kg K/ha. Li and Yen (1988) observed increased top and tuber yield with 60 kg N, 30 kg P and 180 kg K per hectare in Taiwan. More recently, Bonsi and coworkers (1992) stated that recommended fertilizer rates varied 22–146 kg N/ha, 15–100 kg P/ha and 60–210 kg K/ha. Yield of continuous sweet potato was increased from 5.2 to 9.0 t/ha with the application of 225 kg N/ha to a soil with 0.21% total N and 3.3% total organic matter (Bourke 1985).

The great range in P fertilizer requirement for sweet potato may reflect the role of *vesicular arbuscular mycorrhiza* (VAM) in addition to varying P supply in soil. Paterson and colleagues (1987) showed that endomycorrhizal fungus, *Glomus fasciculatum*, improved P uptake by sweet potato, whereas studies by Dowling and colleagues (1995) showed marked responses of sweet potato to applied P in sterilised soil. Kandasamy et al. (1988) and Paula et al. (1992) noted that mycorrhization with *Glomus* spp. improved sweet potato tuber yield and increased N and P accumulation. Floyd and colleagues (1988) found that increased infection with VAM increased yield and reduced response to P fertilizer. Thus, in many respects, sweet potato behaves similarly to cassava (*Manihot esculenta* Crantz), which is also dependent on VAM for P uptake in soils low in P (Howeler et al. 1981). Soil solution P requirements, however, are lower for cassava than for sweet potato or taro (Howeler 1990). Changes in VAM infection would change soil analysis values below which P fertilizer would be recommended.

In India, Mukhopadhyay and Jana (1990) determined an optimum K fertilizer rate of 70–75 kg/ha with a sweet potato tuber yield of around 17 t/ha. Nicholaides et al. (1985) found that yield responses to K fertilizer were obtained with K soil test levels less than or equal to 0.08 cmol/L (Mehlich-I extractant). Continuously cropped sweet potato yield increased from 5.7 to 8.9 t/ha on the application of 375 kg K/ha to a soil with 0.3 cmol K/kg (Bourke 1985). In spite of some reports recommending the use of sulfate (e.g. de Geus 1967), no improvement in yield or quality was evident with the use of the more expensive K_2SO_4 fertilizer. (It was concluded, therefore, that Cl concentration less than or equal to 2.28% in the youngest fully-developed leaf with petiole was not detrimental to sweet potato.) Similarly, Ma and colleagues (1986) reported that yield and quality of tubers were not affected by Cl fertilisation at less than or equal to 190 kg/ha.

Recommended fertilizer rates for taro have varied 60–140 kg N/ha, 25–125 kg P/ha and 80–340 kg K/ha (de Geus 1967). More recent results have indicated similar rates to be appropriate, viz. 40–80 kg N, 10 kg P and 40–80 kg K per hectare for high corm yield, with split applications of N and K (Mohankumar and Sadanandan 1989; Mohankumar et al. 1990). In Hawaii, higher rates of fertilizer of 515 kg N/ha and 670 kg K/ha (Silva et al. 1990) and 250 kg P/ha (Sato et al. 1990) have been recommended. In the former study, adequate leaf concentrations were 4.3–4.5% N and 4.1–4.3% K.

There is much less information on the application of macronutrients, other than N, P and K, or micronutrients, for both sweet potato and taro. More research is clearly needed on the correct identification of disorders in the field, and the fertilizer rates needed to overcome the limitations and optimise the economic return.

Soil Amelioration

The application of lime or gypsum in some circumstances is essential in overcoming the adverse effects of soil acidity on sweet potato and taro production. A number of limitations occur in acid soils, including the presence of toxic concentrations of aluminium (Al) and manganese (Mn) and deficiencies of essential nutrients (e.g. P, Ca, Mg, Mo). This issue has been dealt with in detail by Ila'ava and colleagues (this Proceedings). The adverse effects on plant growth of saline and sodic soils may be overcome through the application of gypsum.

The application of animal manures and composts provides an important means whereby subsistence and semi-subsistence farmers may overcome nutrient limitations, acid soil effects and soil physical limitations. Floyd and colleagues (1988) reported a predominantly linear response of sweet potato to the addition of up to 100 t/ha fresh compost on nine soils in the Highlands of Papua New Guinea. Marketable tuber yield increased 0.035–0.118 t/ha for each tonne of compost added. Unfortunately, there was little residual effect of compost. Phosphorus nutrition was the major factor affecting response to compost which reduced P fixation by volcanic ash soils.

Mulching with leaves of *Erithrina* sp. or with grass (*Panicum maximum* L.) increased taro yield in Western Samoa (Weeraratna and Asghar 1992). An application of up to 60 t/ha leaves of *Erithrina* sp. increased yield from dry matter 1.6 t/ha to 3.2; mulching with grass, however, was less effective, yield increasing to 2.3 t/ha.

Two potential difficulties exist if increased rates of organic materials are to be used for root crop production. Firstly, there would be a likely increase in the 'excessive burden of work for women' (Floyd et al. 1988). Secondly, addition of organic matter would increase the rate of nutrient decline of the land from which the organic materials had been collected.

Conclusion

The correction of nutrient limitations of root crops in the Pacific is made difficult through the lack of information on the nature, extent and severity of nutrition disorders. Additionally, the subsistence or semi-subsistence nature of the farming systems ensures little cash being available for the purchase of fertilizer, lime or gypsum. In spite of these difficulties, identification and correction of nutrient limitations is necessary if soil degradation is to be arrested, particularly with increased intensity of land use.

References

Bonsi, C.K., Bouwkamp, J.C., Hill, W.A. and Loretan, P.A. 1992. Production practices. In: Jones, A. and Bouwkamp, J.C., ed., Fifty Years of Cooperative Sweet Potato Research. Louisiana Agricultural Experiment Station Southern Cooperative Series No. 369. 29–43.

Bourke, R.M. 1985. Influence of nitrogen and potassium fertilizer on growth of sweet potato (*Ipomoea batatas*) in Papua New Guinea. Field Crops Research, 12. 363–375.

Bradbury, J.H. and Holloway, W.D. 1988. Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific. Australian Centre for International Agricultural Research. ACIAR Monograph No. 6. 201 p.

de Geus, J.J. 1967. Fertilizer Guide for Tropical and Subtropical Farming. Centre d'Etude de l'Azote, Zurich. 727 pp.

Dowling, A.J., Blamey, F.P.C. and Hoa, T. 1995. Limitations to sweet potato growth in small volumes of soil imposed by water and nutrient stress, acidity and salinity. Papua New Guinea Journal of Agriculture, Forestry and Fisheries (in press).

Enyi, B.A.C. 1977. Analysis of growth and tuber yield in sweet potato (*Ipomoea batatas*) cultivars. Journal of Agricultural Science, Cambridge, 88. 421–430.

Floyd, C.N., Lefroy, R.D.B. and D'Souza, E.J. 1988. Soil fertility and sweet potato production on volcanic ash soils in the Highlands of Papua New Guinea. Field Crops Research 19. 1–25.

Howeler, R.H. 1990. Phosphorus requirements and management of tropical root crops. Proceedings of a Symposium: Phosphorus requirements for Sustainable Agriculture in Asia and Oceania. 6–10 March 1989. International Rice Research Institute, Manila, Philippines. 427–444.

Howeler, R.H., Edwards, D.G. and Asher, C.J. 1981. Application of the flowing solution culture techniques to studies involving mycorrhizas. Plant and Soil 59. 179–183.

Kandasamy, D., Palanisamy, D. and Oblisami, G. 1988. Screening of germplasm of sweet potato for VA-mycorrhizal fungal occurrence and response of the crop to the inoculation of VAM fungi and *Azospirillum*. Journal of Root Crops, 14. 37–42.

Li, L. and Yen, H.F. 1988. The effects of cultural practices on dry matter production and partition of sweet potato (*Ipomoea batatas*). Journal of the Agricultural Association of China, 141. 47–61.

Ma, G.R., Han, G.Z., Ni, M.X. and Qi, G.K. 1986. A study on the effect of chloride fertilizers to sweet potato. Zhejiang Agricultural Science, 1. 23–24.

Mohankumar, C. R. and Sadanandan, N. 1989. Growth and dry matter accumulation in taro (*Colocasia esculenta* (L.) Schott) as influenced by NPK nutrition. Journal of Root Crops, 15. 103–108.

Mohankumar, C.R., Sadanandan, N. and Saraswathy, P. 1990. Effects of levels of NPK and time of application of N and K on the yield of taro (*Colocasia esculenta* (L.) Schott). Journal of Root Crops, 16. 33–38.

Mukhopdhyay, S.K. and Jana, P.K. 1990. Economics of potassium fertilization of sweet potato. Journal of Potassium Research, 6. 114–118.

Nicholaides, J.J., III, Chancy, H.F., Mascagni, J.J., Jr, Wilson, L.G. and Eaddy, D.W. 1985. Sweet potato response to K and P fertilization. Agronomy Journal, 77. 466–470.

Paterson, D.R., Taber, R.A., Earhard, D.R. and Cushman, K.E. 1987. Response of 'Jewel', 'Topaz' and 'Cordner' *Ipomoea batatas* cultivars to endomycorrhizal fungi in greenhouse and field experiments. Horticultural Science, 22. 1107.

Paula, M.A., Urquiaga, S., Siquera, J.O. and Dobereiner, J. 1992. Synergistic effects of vesicular-arbuscular mycorrhizal fungi and diazotropic bacteria on nutrition and growth of sweet potato (*Ipomoea batatas*). Biology and Fertility of Soils, 14. 61–66.

Sato, D., Silva, J. and Kuniyoshi, J. 1990. Phosphorus fertilisation for dryland taro. Hawaii Institute of Tropical Agriculture and Human Resources Research Extension Series No. 114. 71–77.

Silva, J.A., Sato, D., Leung, P.S., Santos, P.S., Santos, G., Kuniyoshi, J. and Ping-Sun-Leung, A.D. 1990. Reponse of Chinese taro (*Colocasia esculenta* (L.) Schott var. 'Bun Long') to nitrogen and potassium fertilization. Hawaii Institute of Tropical Agriculture and Human Resources Research Extension Series No. 114. 60–70.

Weeraratna, C.S. and Asghar, M. 1992. Effects of grass and dadap mulches on soil (an Inceptisol) properties and yield of taro (*Colocasia esculenta*) in Western Samoa. Tropical Agriculture, 69. 83–87.

Yoshida, T., Hozo, Y. and Murato, T. 1970. Studies on the development of tuberous roots in sweet potato (*Ipomoea batatas* (L.) Lam). The effect of deep displacement of mineral nutrients on the tuberous root yield of sweet potato. Proceedings of the Crop Science Society of Japan, 34. 105–110.

The Response of *Colocasia esculenta* (L.) Schott and *Xanthosoma* sp. to Phosphorus Fertilizer on Selected Soils of Western Samoa: A Progress Report

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Abstract

Five sites comprising freshly cleared land, or similar land exhausted by cropping, were selected for fertilizer experiments on the basis of previously conducted pot experiments which indicated all sites to be strongly P-deficient.

At Laloanea, experiments with *Colocasia* in 1993 showed that large increases in corm yield could be obtained with broadcast applications of P as TSP, these effects being enhanced by the application of lime or *Erythrina* mulch. In 1994, responses to the treatments were limited by taro leaf blight, but the trends were similar.

In the latter part of 1994, P fertilizer trials with blight-resistant *Xanthosoma* were planted at Lalaonea, Afiamalu and Alafua. At the first two locations, paired sites were used so that the effects of nutrient depletion through cropping would be compared. In these trials, effects of fertilizer placement are being studied also. Visual observation of these trials, still in progress, again indicate substantial responses to P fertilizer.

WESTERN Samoan soils contain high amounts of oxides of aluminium (Al), iron (Fe) and titanium (Ti) (Asghar 1988). These factors contribute to the high P fixation by Western Samoan soils reported by Morrison and coworkers (1986) and Asghar (unpublished, 1985). Many researchers have reported that application of P fertilizers can increase taro yields in similar P-fixing soils (Sato et al. 1990; Enyi 1968; de la Peña 1967).

Experiments conducted in Samoa have shown large responses of taro to inorganic fertilizers (Reynolds 1971, 1977; Van Wissen and Masipa'u, 1978 a,b; Cable 1979).

The present study investigates the responses of *Colocasia esculenta* and *Xanthosoma* sp. to phosphorus fertilizer in selected high P-fixing soils based on results obtained in a series of pot experiments reported elsewhere.

The research objectives are: (i) to study the effects of P fertilizer applications on taro yields; (ii) to compare the effects of *Erythrina* sp. mulch over the effects of P fertilisation; and (iii) to identify the role played by lime amendments on taro yields.

Materials and Methods

Field trials were established at three locations on the Island of Upolu, Western Samoa. Laloanea (12 km southwest of Apia) and Afiamalu (18 km south of Apia) had two experimental sites each, a continuously cropped (CC) site, and a recently cleared (RC) site, while Alafua (5 km south of Apia) has only a CC site. The Laloanea CC site had been abandoned after cropping taro for seven years due to low fertility, whereas the Laloanea RC site had just been cleared for taro cropping after six years fallow. The results from nutrient omission pot trials revealed that the two Laloanea sites were deficient in N and P (RC site moderately and CC site severely). Therefore it was decided to conduct a field trial using different rates of P from triple superphosphate (TSP) with N supplied as a mulch of dadap (*Erythrina* sp.), a popular mulching material used by Western Samoan farmers.

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Field Trials with *Colocasia esculenta* as the Test Plant

It is important to mention that Samoan farmers are not used to applying fertilizers to taro, thus any such recommendation must be economically feasible and socially accepted by them. They also believe that the application of N fertilizers would reduce corm quality and taste. However, they are used to the application of mulches, especially *Erythrina* sp. Based on plant analysis, a mulch of *Erythrina* at the rate of 45 t/ha fresh material would add 476 kg N, 45 kg P, 270 kg K, 63 kg Ca, 35 kg Mg, 0.5 kg Fe, 1.2 kg Mn, 0.5 kg Zn and 0.2 kg Cu to each hectare treated.

The first trial was established on 24 February 1993 and harvested 28 August 1993. Details of the treatments for both the CC and RC sites are shown in Table 1. The plot size was 55 m, plant density 20/plot (11m), these 6 replicated, and laid out as a randomised complete block design. Phosphorus was applied as TSP broadcast at planting, agricultural lime was broadcast two weeks before planting, and the *Erythrina* mulch applied in three equal portions, one, three and five months after planting.

In the second field trial, the best-yielding treatments from the first experiments were repeated to verify the results. This second field trial was planted in May 1994 and harvested in December 1994. Plot size, plant density and replication were as for trial 1. This phase of the project was considerably impaired by the taro leaf blight epidemic which started in mid-1993. Leaf blight control measures were carried out in accordance with the Department of Agriculture, Forestry, Fisheries and Meteorology (DAFFM) recommendations, but good control was not achieved, resulting in poor growth and low yields.

Field Trials with *Xanthosoma* sp. as the Test Plant

Due to the heavy infestation of taro leaf blight and the severe reduction in yield and corm quality, the farmers of Western Samoa were still reluctant to grow taro (during mid-1994) despite the promotional activities of DAFFM. For many farm situations, fungicides are expensive and the labour not adequate to carry out manual sanitary control measures. Therefore it was decided to switch the test plant to *Xanthosoma* sp., which is not severely affected by the blight and also was becoming popular among farmers. *Xanthosoma* yields are attractive and the crop has potential for export. Also, it was realised that broadcast P application at Laloanea (a high P-fixing site) was probably inappropriate. Hence, in the *Xanthosoma* trials, two methods of fertilizer application were used: (i) spot application in the planting hole, and (ii) surface ring application around the plant. At each site, five P rates were used (0, 45, 90, 180, and 360 kg/ha) with triple superphosphate (TSP) as the P source. *Erythrina* fresh mulch at a rate of 25 t/ha was applied in two doses (six weeks and three months after planting) to all plots including checks except for the Afiamalu RC site. At all sites plot size was 67.5 m with a plant density of 20/plot at 1.5 × 1.5 m spacing. The design was randomised complete block with six replicates.

At Laloanea, a new location close to the CC site was selected for the *Xanthosoma* trial, the design for treatments being as indicated above. At the Afiamalu CC site, which had been found to be deficient in a number of micronutrients (Fe, Mn, Zn, Cu, and Mo) plus magnesium, a shotgun application of Mg at 10 kg/ha, Fe at 5, Zn at 4, Mn at 5, Cu at 3 and Mo at 0.4 kg/ha were applied to all planting holes including checks at planting. For the Afiamalu site, *Erythrina* mulch was not applied so a supplement of muriate of potash (KCl) at 50 kg/ha was applied to all planting holes. For the Alafua CC site supplements of Mg at 10 kg/ha and Cu at 3 and Ni at 0.1 kg/ha were added to the planting holes to all plots including checks at planting.

Table 1. Fresh yield of taro corms (t/ha).

Trial 1				Trial 2			
Tmt		Tmt		Tmt		Tmt	
P45	3.0	P30	3.8	—	—	—	—
P90	3.8	P60	4.4	—	—	—	—
P135	5.3	P90	5.9	P135	2.13	P90	2.24
P90 + M45	6.5	P60 + M45	6.4	P90 + M45	2.83	P60 + M45	3.34
P90 + L5	5.1	P60 + L3	5.4	P90 + L5	2.30	P60 + L3	2.56
check	2.3	check	2.9	check	1.47	check	1.52
LSD0.05	0.57	LSD0.05	0.83	LSD0.05	0.67	LSD0.05	1.00

Tmt = treatment, P45 etc. = TSP at 45 kg P/ha, M45 = *Erythrina* mulch at 45 t/ha, L5 etc. — lime at 5 t/ha.

Results and Discussion

Colocasia trials

The results of previous soil test and pot trials had indicated that Laloanea soils are deficient in N, P and K. In the first trial for the Laloanea sites, P application consistently increased the yield of taro (*Colocasia esculenta*) corms (Table 1) in both the CC and RC sites. The *Erythrina* mulch (M45) was more effective in the CC site (3.9% organic C) than in the RC site (9.1 organic C). The yield increase between P90 and P90 + M45 was around 70%, indicating the positive contribution of mulch. As the mulch contributed an additional 45 kg P/ha some of this response was probably due to the extra P added. However, since in trial 1 corm yields were significantly greater in the P90 + M45 treatment than in the P135 treatment, the effects of the mulch could not have been due to the extra P applied. The amendment with lime was reasonably effective in increasing the efficiency of the applied P. The yield increase between P90 and P90 + L5 treatments was around 34%.

In the second trial P application significantly increased the yield of taro (*Colocasia esculenta*) corms at both sites when lime or mulch was also applied (Table 1). Although the results indicated similar trends as in the previous experiment, the yields were markedly reduced by the taro leaf blight (*Phytophthora colocasiae*) that severely affected plant growth despite the use of DAFFM-recommended control measures. The newly recommended chemical 'Foscheck' (mono- and di-potassium phosphonate) for blight control was available only for the final two months of the experiment, but by then it was too late to have any significant impact on growth response, as the plants were in senescence.

Xanthosoma trials

The Laloanea trial will be harvested in mid-March 1995, the Alafua trial in the third week of May 1995, the Afiamalu CC site at the end of May 1995, and the Afiamalu RC site in the first week of June 1995. At the time of reporting, symptoms of K and P deficiency were prominent in the check plots at both Laloanea and Alafua.

Treatment effects were also prominent in the Laloanea and Alafua sites where the highest P application rates show the most vigorous growth. Treatment effects were just beginning to show in the Afiamalu CC site which was similar to the Alafua and Laloanea sites. The crop at Afiamalu RC site was still too early in growth stages to show any visible treatment effects at the time of this report.

Conclusions

Results of the present study confirmed that P deficiency, indicated from soil analysis and pot culture studies, limited the yield of two sites under field conditions. Broadcast applications of TSP were effective in increasing yields, but trials currently in progress suggest that spot placement or bonding may be preferable at the continuously cropped Laloanea site. *Erythrina* mulch increased the yield by more than would be expected on the basis of its P content.

The trials indicated that *Erythrina* sp. is a good source of mulching material for taro. It is freely available in Western Samoa, farmers are familiar with it, and its use can provide a valuable low-cost source of mineral nutrients which should help limit fertilizer costs in Western Samoa.

This study brings hope that continuously cropped land can be as profitable as recently cleared land if suitable inputs of mineral nutrients are made. This may help to lessen the incidence of shifting cultivation and the associated pressures to clear remaining areas of forest for food crop production.

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References

Asghar, M. 1985. Management as a factor in maintaining and enhancing the fertility of soils in Western Samoa (unpublished manuscript).

— 1988. The nature and properties of Western Samoa soils. In: Asghar, M., Davidson Jr, T.J., Morrison, J.R. ed., 1988, Soil Taxonomy and Fertility in the South Pacific. Proceedings of the XV International Forum on Soil Taxonomy and Agrotechnology Transfer, USP/IRETA, Apia, Western Samoa.

Cable, W.J. 1979. The fertilizer requirement of taro (*Colocasia esculenta* (L.) Schott cv. Niue) on a Typic Haplothorx in Western Samoa. Misc. Publ. 5/79, School of Agriculture, USP-Alafua Campus, Apia, Western Samoa. 22 p.

de la Peña, R., Plucknett, D.L. 1967. The response of taro (*Colocasia esculenta* (L.) Schott) to N, P, and K fertilization under upland and lowland conditions in Hawaii. In: Tai et al., 1967, Proceedings of the International Symposium on Tropical Root Crops. University of the West Indies, Trinidad. II-70 to II-80.

Enyi, B.A.C. 1968. Growth of cocoyam (*Xanthosoma sagittifolium* Schott). Indian Journal of Agricultural Science, 38. 627–633.

Morrison, R.J., Prasad, R.A., Asghar, M. 1986. Taxonomy of Some Western Samoa Benchmark Soils. Environment Studies Report no. 28, Institute of Natural Resources, University of the South Pacific, Suva, Fiji. 65 p.

Reynolds, S.G. 1971. A report on a number of taro fertilizer trials conducted in Western Samoa, 1969–1970. Research Paper Series No. 15, South Pacific Regional College of Tropical Agriculture (SPRCTA), Alafua, Western Samoa. 19 p.

— 1977. A study of the growth period of the taro plant (*Colocasia esculenta* (L.) Schott cv Niue) in Western Samoa. In: Regional Meeting on the Production of Root Crops: collected papers (Conference Regionale de la Production des Plantes a Racines Alimentaires documents de travail). SPC Technical Paper No. 174. SPC, Noumea, New Caledonia. 62–67.

Sato, D.M., Silva, J., Kuniyoshi, J. 1990. Phosphorus fertilization for dryland taro. In: Hollyer, J.R., Sato, D.M. ed. 1990. Proceedings of taking taro into the 1990s: a taro conference. College of Tropical Agriculture, University of Hawaii, Hawaii. Research Extension Series, 114. 71–85.

Van Wissen, H.L.M., Masipa'u, T. 1987a. The effect of time of application of fertilizer on yield and quality of taro (*Colocasia esculenta* (L.) Schott cv. Niue). Working paper No. 7 (revised), DAFF/GWS, Apia, Western Samoa. 12 p.

— 1987b. The effect of time of application of fertilizer on yield and quality of taro (*Colocasia esculenta* (L.) Schott cv. Niue). Working paper No. 10, DAFF/GWS, Apia, Western Samoa. 16 p.

Effects of Potassium on Drought Tolerance of Taro and Tannia

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Abstract

Effects of potassium supply on tolerance of taro and tannia to water stress were studied in a glasshouse pot experiment to determine whether K nutrition affected the ability of these aroids to withstand drought. Plants with sufficient K were found to have better stomatal control during the day when evaporative demand was high, and hence were able to restrict water loss and maintain a more favourable water balance in leaf tissue than plants deficient in K. Both K deficiency and water stress reduced leaf area and root and total plant weights, but there was no interaction between K and water stress. Water-use efficiency was also lower in plants deficient in K.

THE edible aroids, taro (*Colocasia esculenta* L. Schott) and tannia (*Xanthosoma sagittifolium* L. Schott) are important food crops of the wet tropics. *Colocasia esculenta* contains two botanical varieties, dasheen (var. *esculenta*) and eddoe (var. *antiquorum*), of which eddoe is regarded as the more drought-tolerant (Purseglove 1975). Tannia is regarded as more drought tolerant than taro (Purseglove 1975).

Crops grown under dryland conditions, even in the wet tropics, often have to tolerate intermittent drought, which can occur at any time between planting and harvest, and may vary greatly in intensity (Ludlow and Muchow 1990). Since the aroids are grown mostly as dryland crops, their ability to survive and yield well in situations of intermittent water stress is extremely important.

The aroids are usually grown in the Pacific islands without fertilizers. They have high requirements for potassium (K) and large yield responses to this element have often been obtained in field experiments (de la Peña and Plucknett 1967; Ashokan and Nair 1984). It is now well recognised that K plays an important role in turgor maintenance and regulation, and in stomatal movement in plants (Beringer and Nothdurft 1985; Hsiao and Lauchli 1986). Plants well supplied with K have been reported to tolerate water stress better than plants deficient in K (Losch et al. 1992).

The objective of the present project was to investigate whether adequate K nutrition would improve the tolerance of taro and tannia to water stress.

Methods

One cultivar each of tannia (Xs01) and eddoe (Ce02), and two dasheen cultivars, one of which had been found in an earlier experiment to be drought-tolerant (Ce139) and the other, drought-susceptible (Ce91), were used in this study. A factorial experiment was conducted in a glasshouse, in which four cultivars were grown at three rates of K and two levels of water supply. Treatments were arranged in a randomised complete block design with four replications. The plants were grown in undrained 25 L pots containing 20 kg of UC potting mixture that was prepared with all the plant nutrients that are normally supplied except K.

Potassium was applied in solutions as a 1:1 mixture on molar basis of $KN0_3$ and KCl at 0 (K0), 2 (K1), and 5 (K2) K g/pot (equivalent to 0, 280, and 700 K kg/ha). Peat used in the potting mixture contained about 1.7 of K g/pot. Ammonium nitrate was used to balance nitrogen (N) applied as $KN0_3$.

All plants were raised in pots watered daily to near field capacity for the first 70 days. Thereafter, one half of the pots continued to receive adequate water (U), the potting mixture kept at near-field

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capacity by watering every evening. In the other pots, the plants were subjected to a slowly developing water stress (S). Water was added to these pots if the plants used more than 170 water mL/day so that the initial water content in the pots on each successive day was no more than 170 mL below that of the previous day.

Effects of K and water stress on leaf area development and retention, leaf number, leaf size, stomatal conductance, leaf water potential (ψ), water use, and water-use efficiency (WUE) were investigated. The experiment was harvested 22 days after imposition of water stress (DAS) and dry weights determined. The lamina of the second fully open leaf was analysed for K and sodium (Na) by Inductively Coupled Plasma Atomic Emission Spectrometry.

Results and Discussion

Effects on leaf potassium and sodium

At harvest, the mean K concentration in the index leaf across all cultivars and water levels increased from 1.77% at K0, to 2.78% at K1 and 3.42% at K2. Mean K concentration across all K treatments and water levels in tannia (2.29%) and Ce139 (2.42%) was lower than those in eddoe (2.88%) and Ce91 (3.07%).

The Na concentration was considerably higher in tannia (0.94%) than in taro (0.01%). In tannia, the Na concentration decreased from 1.35% to 0.76% and 0.71% as the K concentration increased from 1.48% to 2.45% and 2.94%. In contrast, the Na concentration in taro was unaffected by K status. The possibility of partial substitution of Na for K in tannia deserves further investigation.

Effects on dry matter yield

The response to K application was similar in all aroid cultivars. Hence, yield data have been meaned across cultivars (Table 1). In the absence of water stress, comparison of total plant dry weights of K0 and K2 plants showed that K deficiency reduced plant weight by 19%. In the presence of adequate K (K2), water stress reduced plant weight by 13%. The interaction between K and water level was not significant, indicating that K deficiency and water stress reduced plant dry matter independently. Plant weight of water-stressed K0 plants was 35% lower than unstressed K2 plants.

In the absence of water stress, root weight of K0 plants was 25% lower than that of K2 plants. In the presence of adequate K, water stress reduced root weight by 19%. The interaction between K and water stress on root weight was also not significant.

Table 1. Effects of potassium (K0, K1 and K2 equivalent to 0, 280 and 700 kg/ha) on total plant and root weights of water-stressed (S) and unstressed (U) plants meaned across cultivars at harvest.

Rate of K	Total plant weight (g)		Root weight (g)	
	U	S	U	S
K0	107.8c	87.1a	19.6b	17.9a
K1	120.0d	92.0ab	23.1cd	19.2ab
K2	132.5e	100.1bc	26.1d	21.9bc
Mean	120.0	93.1	22.9	19.7

Within the total plant weights and root weights, values with different letters are significantly different at LSD ($P<0.05$).

Leaf number, size and area

Potassium deficiency reduced leaf size, and final leaf number and leaf area of the aroids (Table 2). In the absence of water stress, leaf number, leaf size and leaf area were reduced in the K0 treatment by 18%, 31% and 25% respectively compared to the K2 treatment. In the presence of adequate K, water stress reduced leaf number, leaf size and leaf area by 20%, 32% and 37% respectively. There was no interaction between K and water stress on leaf size or leaf area.

Potassium is highly mobile in plants, and under deficiency, K is mobilised from the older leaves for use in the rapidly growing regions of the plant (Mengel and Kirby 1987). It appears that in plants deficient in K, relocation of K from old to young leaves resulted in early senescence of leaves with consequent reduction in leaf number.

Cell extension and plant growth are very sensitive to K deficiency as it has been shown that cell turgor plays a vital role in cell expansion and that K may reduce growth through its effect on cell turgor in K-deficient plants (Bradford and Hsiao 1982). The results of the present study showed that both reduction in leaf expansion and premature senescence of leaves caused the reduction in leaf area of aroids under K deficiency. The results also showed that in the presence of sufficient K, the plants were able to retain a much higher leaf area than K deficient plants when subjected to water stress.

Stomatal conductance

Midday stomatal conductance of water-stressed K2 plants was significantly lower than in water-stressed K0 plants early in the water stress period (4, 7, 11 DAS) but after 14 DAS when the water stress became severe there were no differences among the K treatments (Fig. 1). Midday stomatal conductance of unstressed K2 plants also tended to be lower than unstressed K0 plants, the difference being significant at 7 and 17 DAS.

Table 2. Effects of potassium (K0, K1 and K2 equivalent to 0, 280 and 700 kg K/ha) on final leaf number and area, and size of leaf produced between 7 and 14 DAS of water-stressed (S) and unstressed (U) plants meaned across cultivars.

Rate of K	Total leaves/plant		Leaf size (cm^2)		Leaf area/plant (cm^2)	
	U	S	U	S	U	S
K0	4.13bc	3.19a	911b	693a	3665c	2378a
K1	4.50c	4.06b	1197c	901b	4089c	2709a
K2	5.25d	4.19bc	1329c	904b	4862b	3066b
Mean	4.69	3.81	1146	832	4205	2718

Within the values for total leaves/plant, leaf size and leaf area/plant, those with different letters are significantly different at LSD (P<0.05).

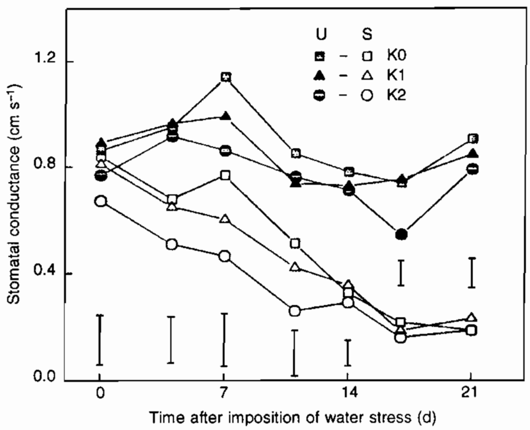

Fig. 1. Effects of potassium (K0, K1, and K2 equivalent to 0, 280 and 700 kg K/ha) on midday stomatal conductance of unstressed (U) and water-stressed (S) plants meaned across cultivars. Vertical bars indicate LSD (P<0.05).

These results show that stomatal conductance of plants with sufficient K was generally lower than that of K-deficient plants at midday when the evaporative demands were high. It appears that in plants with sufficient K, the stomata closed more completely than in K-deficient plants when evaporative demands increased during the day, thereby reducing water loss at a critical time of day. In contrast, in K-deficient plants the stomata closed to a lesser extent at midday, resulting in a relatively higher loss of water. Similar stomatal response to K has been reported from field-grown barley by Losch and co-workers (1992). They found that stomatal conductance was reduced more under water stress in K-sufficient plants than in plants deficient in K.

Leaf water potential

Potassium did not affect predawn ψ in the aroids (Fig. 2). In water-stressed plants, predawn ψ under all K treatments decreased as severity of water stress increased. Although the water-stressed K2 plants had a higher midday ψ than water-stressed K0 plants at 14 DAS, this difference was not consistent (K0 was intermediate between K1 and K2), and there was no difference between these treatments at 21 DAS (Fig. 2).

Midday ψ of unstressed K0 and K1 plants were generally lower than K2 plants but the differences were not significant. However, midday ψ of water-stressed K0 plants was lower than that of the K2 plants at 14 and 21 DAS. Lower midday ψ of K-deficient plants than plants sufficient in K provided further evidence that, under K deficiency, the aroid plants lost water more rapidly during the day.

Water use and water-use efficiency

Total water use was not affected by K treatments. However, water-stress reduced total water use from 22.4 L to 16.9 L. Although the K-deficient aroid plants had a much lower leaf area, they used as much water as K-sufficient plants, providing further evidence of poor stomatal control under K deficiency.

Under both unstressed and water-stressed conditions, the WUE of K2 and K1 plants was significantly higher than that of K0 plants (Table 3). The WUE of K2 plants was about 22% higher than that of K0 plants. Cable (1973) also reported that application of a high rate of K improved WUE in taro. Various reasons including loss of transpirational control due to sluggish closing of stomata have been cited as the cause for low WUE under K deficiency (Hsiao and Lauchli 1986). Over 50 plant enzymes, including those catalysing phosphoryl transfer reactions on photosynthesis and those catalysing elimination and hydrolytic reactions involved in cell wall synthesis and cell expansion, are known to be activated by K (Suelter 1985). Potassium deficiency has been shown to reduce the rates of photosynthesis

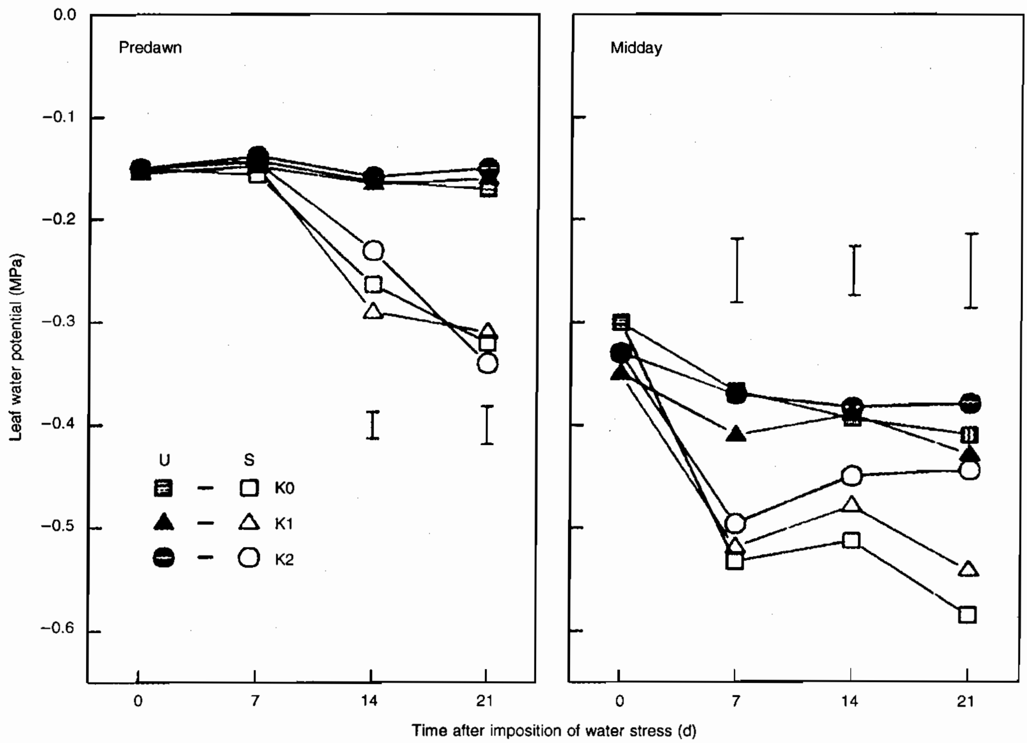

Fig. 2. Effects of potassium (K0, K1, and K2 equivalent to 0, 280, and 700 kg K/ha) on predawn and midday leaf water potential of unstressed (U) and water-stressed (S) plants meaned across cultivars. Vertical bars indicate LSD (P<0.05).

and translocation and increase the rate of dark respiration (Huber 1985). Reduction in plant growth through the effects of K on these enzymes plus reduced leaf area duration probably also contributed to the low WUE of K-deficient plants.

Table 3. Effects of potassium (K0, K1 and K2 equivalent to 0, 280 and 700 kg K/ha) on water use efficiency of water-stressed (S) and unstressed (U) plants meaned across cultivars.

Rate of K	Water-use efficiency (g/L)		Mean
	U	S	
K0	4.93a	5.33a	5.13a
K1	5.86b	5.88b	5.87b
K2	6.02b	6.55c	6.29c
Mean	5.60	5.92	

Within the values for water-use efficiency, and K mean, those with different letters are significantly different at LSD (P<0.05).

Conclusions

Evidence from this study shows that K-sufficient aroid plants have better stomatal control during the day when evaporative demand is high, and hence are able to restrict water loss and maintain a more favourable water balance in leaf tissues than plants deficient in K. As a consequence, K-sufficient aroid plants retained a higher leaf area, and had higher root and plant weights at the end of water stress periods than K-deficient plants. The WUE was also higher in plants with sufficient K.

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References

Ashokan, P.K. and Nair, R.V. 1984. Response of taro (*Colocasia esculenta* L. Schott) to nitrogen and potassium. Indian Journal Root Crops, 10. 59–63.

Beringer, H. and Nothdurft, F. 1985. Effects of potassium on plant and cellular structures. In: Munson, R.D. ed. Potassium in Agriculture. ASA-CSSA-SSSA, Madison, Wisconsin, USA. 352–368.

Bradford, K.J. and Hsiao, T.C. 1982. Physiological responses to moderate water stress. Encyclopedia Plant Physiology, New Series 12C. 263–324.

Cable, W.J. 1973. Potassium requirement of taro in relationship to growth, foliar analysis, yield and quality as grown in solution culture. Proceedings Third International Symposium Tropical Root Crops, IITA, Ibadan, Nigeria. 130–137.

de la Peña, R.S. and Plucknett, D. 1967. The response of taro (*Colocasia esculenta* L. Schott) to N, P and K fertilisation under upland and lowland conditions in Hawaii. Proceedings First International Symposium Tropical Root Crops, University of West Indies, Trinidad, 1 (11). 70–85.

Hsiao, T.C and Lauchli, A. 1986. Role of potassium in plant water relations. Advance Plant Nutrition, 2. 281–312.

Huber, S.C. 1985. Role of potassium in photosynthesis and respiration. In: Munson, R.D., ed. Potassium in Agriculture. ASA-CSSA-SSSA, Madison, Wisconsin, USA. 369–398.

Losch, R., Jensen, C.R. and Andersen, M.N. 1992. Diurnal courses and factorial dependencies of leaf conductance and transpiration of differently potassium fertilised and watered field grown barley plants. Plant Soil, 140. 205–224.

Ludlow, M.M. and Muchow, R.C. 1990. A critical evaluation of traits for improving crop yields in water-limited environments. Advance Agronomy, 43. 107–153.

Mengel, K. and Kirby, E.A. 1987. Principles of Plant Nutrition. International Potash Institute, Berne, Switzerland. 655 p.

Purseglove, J.W. 1975. Tropical Crops: Monocotyledons. Longman Group Ltd, London. 607 p.

Suelter, C.H. 1985. Role of potassium in enzyme catalysis. In: Munson, R.D., ed. Potassium in Agriculture. ASA-CSSA-SSSA, Madison, Wisconsin, USA. 337–350.

The Relationship Between Balanced Nutrition and Disease Susceptibility in Polynesian Taro

R. Tilialo[1], D. Greenough[1], and E. Trujillo[2]

Abstract

Taro leaf blight caused by *Phytophthora colocasia* is one of the most destructive diseases of *Colocasia esculenta* throughout the Pacific basin and has been responsible for the progressive loss of the favoured staple food in Micronesia, Melanesia and Polynesia. Nutrition is known to play a significant role in *Phytophthora*-induced diseases in many crop plants. However, there is a paucity of information regarding the effect of nutrients on the incidence of taro leaf blight.

In American Samoa and other island countries where traditional farming systems use no additional fertilizers, the disease devastates the crop. Many of these traditional farming systems utilise organic mulches, which suggests the mulch alone may not offer sufficient nutrition to the plant under attack. This is a preliminary report on the evaluation of balanced nutrition in a sustainable, integrated management strategy to reduce the incidence of taro leaf blight.

THIS paper is a preliminary report on the first phase of a study funded by Agriculture Development in the American Pacific (ADAP) using sustainable, integrated cultural management systems for the major plant disease of taro. Sustainable agriculture is defined as low-input farming systems that maintain and enhance soil productivity, that minimise environmental contamination by reducing inputs of synthetic pesticides and fertilizers, and that enable the grower to utilise an integrated concept for disease management.

Taro leaf blight caused by *Phytophthora colocasia* is one of the most destructive diseases of taro throughout the Pacific basin and has been responsible for the progressive loss of the favoured staple food in Micronesia, Melanesia, and Polynesia (Jackson and Gollifer 1975; Trujillo and Aragaki 1964; Trujillo 1967). The pathogen is host-specific, attacking *Colocasia* spp. and *Alocasia macrorrhiza* taro.

Control of this disease has been limited to use of fungicides (Berquist 1972; Greenough et al. 1994; Jackson and Gollifer 1975; Trujillo and Aragaki 1964; Trujillo 1967) in severe outbreaks. Sanitation by removing lesions from infected leaves is labour-intensive, non-traditional, and difficult to implement. Chemical control of leaf blight of taro, although successful in advanced agricultural systems, is not readily adaptable to subsistence agriculture. Chemicals are expensive, supply is not available on demand, and fungicides are less effective under heavy rainfall conditions. Efforts to develop breeding programs which introduce resistance to the fungus in agronomic varieties have been successful in Solomon Islands and Papua New Guinea. However, these resistant taro varieties cannot be brought to other areas of the Pacific because of two virus diseases not yet present in Polynesia (Jackson and Gollifer 1975; Strauss 1984). An integrated pest management system using tolerant or resistant varieties from Micronesia and Hawaii, coupled with mineral nutrition and judicious use of fungicides, may provide the strategy needed to cope with this disease in American Samoa.

Nutrition is known to play a significant role in *Phytophthora*-induced diseases in many crop plants (Bingham et al. 1958; Falcon et al. 1984; Lee and Zentmyer 1982; Silva and Sato 1993). There is, however, no information on the effect of nutrients on the incidence of taro leaf blight. Observations made of

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atoll culture suggest that this pathogen is not severe on taro grown in calcium-rich soils. In Guam and Saipan, during weather favourable for disease development, taro leaf blight is not very destructive. These islands have soils rich in calcium, and are rarely fertilised. In Hawaii, growers are able to achieve high yields of taro by using ample supplies of N, P, K, and Ca in the presence of high disease incidence and lack of fungicide sprays.

In American Samoa and other island countries where traditional farming systems use no additional fertilizers, the disease devastates the crop. Many of these traditional farming systems utilise organic mulch systems, which suggests that the mulch alone may not offer sufficient nutrition to the plant under attack.

Methods and Materials

The effects of balanced N, P, K, and Ca nutrition on the taro and the incidence of leaf blight disease are being evaluated using recommendations for Hawaii dry land taro fertilisation developed by Silva and Sato (1993). A randomised split plot design was used with fertilizer treatments as the main effects and resistant/tolerant varieties as secondary effects. Disease control with fungicide applications and sanitation to lower inoculum was also evaluated. Plant growth, development, and yields were recorded and analysed. Plant tissue analysis to monitor levels of N, P, K, and Ca was done and a disease index based on the percentage of leaf loss was developed to measure disease incidence ratings.

Results and Discussion

Preliminary statistical analysis by analysis of variance (ANOVA) with multiple comparisons and means separation by least significant difference (LSD) at the 0.01% level indicates that both the fertilizer treatments and the variety types were significantly different. There were no interactions found among the treatments and varieties.

The mean number of functional leaves per plant over the course of the study was less than three (Fig. 1). The fertilizer or chemical treatment provided the greatest number of healthy, functional photosynthetic leaves in three varieties: Lehua Maoli, Manu'a, and Niue. The non-fertilizer/chemical treatment provided the second greatest number of functional leaves in all varieties. The fertilizer/non-chemical treatment provided the smallest number of functional leaves in Manu'a, Bun Lon, and Niue. Among the varieties, Bun Lon had the greatest number of functional leaves per plant.

The mean number of infected taro leaves per plant throughout the infection period was less than two (Fig. 2). The greatest number of infected leaves per plant occurred in the fertilizer treatments in three varieties: Lehua Maoli, Manu'a, and Bun Lon. The least number of infected leaves per plant of Lehua Maoli were found in the fertilizer/chemical and non-fertilizer/chemical treatments. For the varieties of Manu'a, Bun Lon, and Niue, the least number of infected leaves were in the control.

The highest percentage of leaf loss per plant occurred in the fertilizer/nonchemical treatment plots, ranging from 40–50% of the leaf destroyed by lesions, which was not significantly different from the control (Fig. 3). The lowest percentage of leaf loss was in the fertilizer/chemical treatment for all varieties and was significantly different from the control treatments.

The fertilizer treatments produced significantly greater corm weights at harvest compared to the control for three varieties: Lehua Maoli, Bun Lon, and Niue (Fig. 4). The non-fertilizer/chemical treatment gave the greatest corm weights of this trial, of over 0.5 kg, in the Manu'a variety. The lowest weights of harvested corms were in the non-fertilizer/chemical and control treatments.

The preliminary data indicate that the fertilizer treatments are assisting the taro plants to produce functional leaves in most of the four varieties studied in this first phase. However, the data also indicate that the fertilizer treatments may also be favouring the fungal pathogen development and serving as a contributing factor in loss of foliage due to leaf lesions. The chemical treatments appear to be the most important influence in the protection of the plant during this trial.

The factors influencing the response of the plant to the fertilizer treatments are most likely the time of application, getting the nutrients worked into the soil around the developing root system, and the rainfall experienced immediately after fertilizer application.

In this initial trial, the first application was applied at one month after planting and every month thereafter until the fifth month. The nutrients were manually worked into the upper 50–70 cm (3–4 inches) of soil surrounding the taro plants until no residue could be observed. The entire trial was conducted during the rainy season in American Samoa from late August to late February, when average daily rainfall frequently measures 200–300 mm (10–15 inches) and taro leaf blight infection is at its worst, with high disease pressure.

Research is continuing with the second trial commencing in early June. The same varieties of taro will be used, with the addition of two varieties from Palau which have shown to have excellent resistance to the taro leaf blight fungus in Palau and Hawaii under similar environmental conditions.

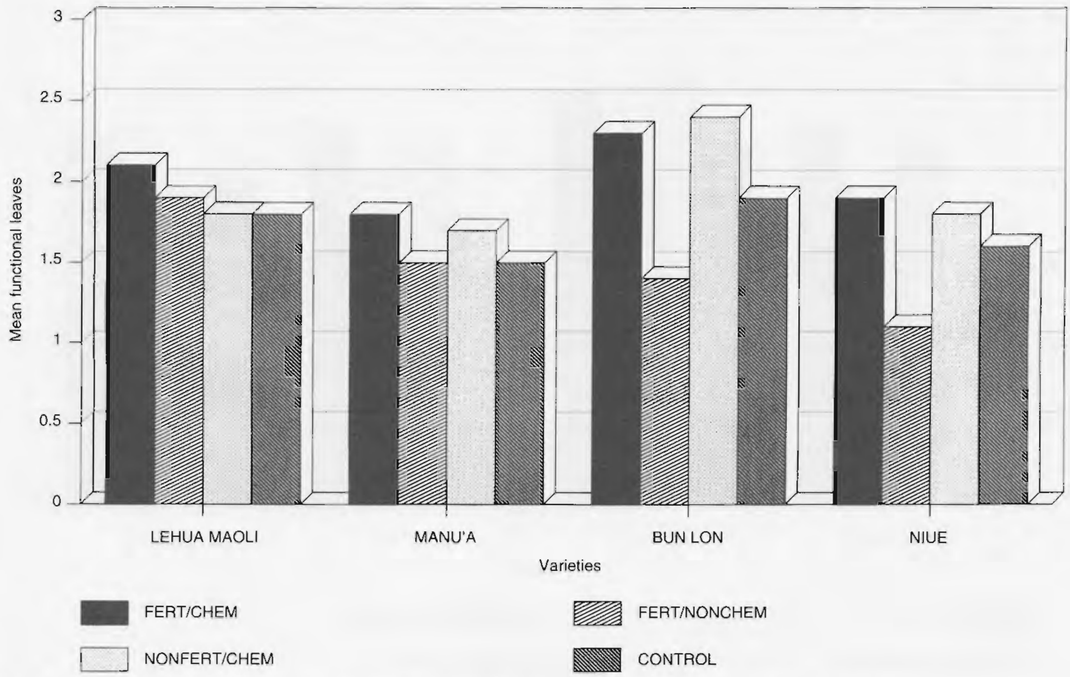

Fig. 1. Mean number of functional *Colocasia esculenta* leaves during *Phytophthora colocasia* infection.

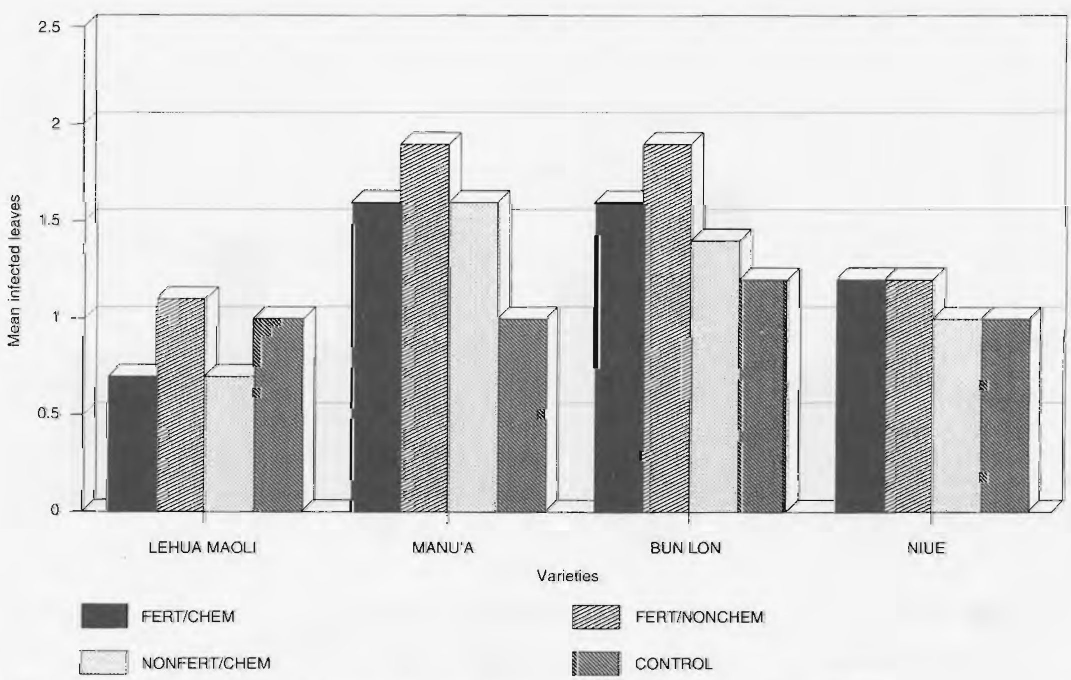

Fig. 2. Mean number of infected *Colocasia esculenta* leaves during *Phytophthora colocasia* infection.

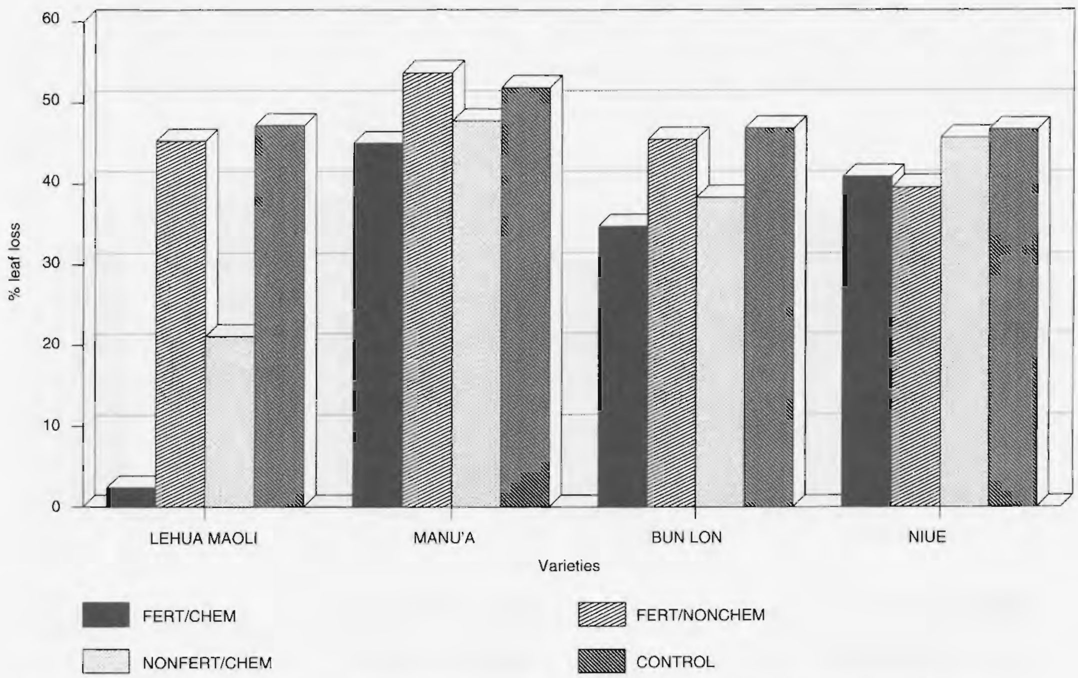

Fig. 3. Percentage of functional leaf loss of *Colocasia esculenta* due to *Phytophthora colocasia* infection.

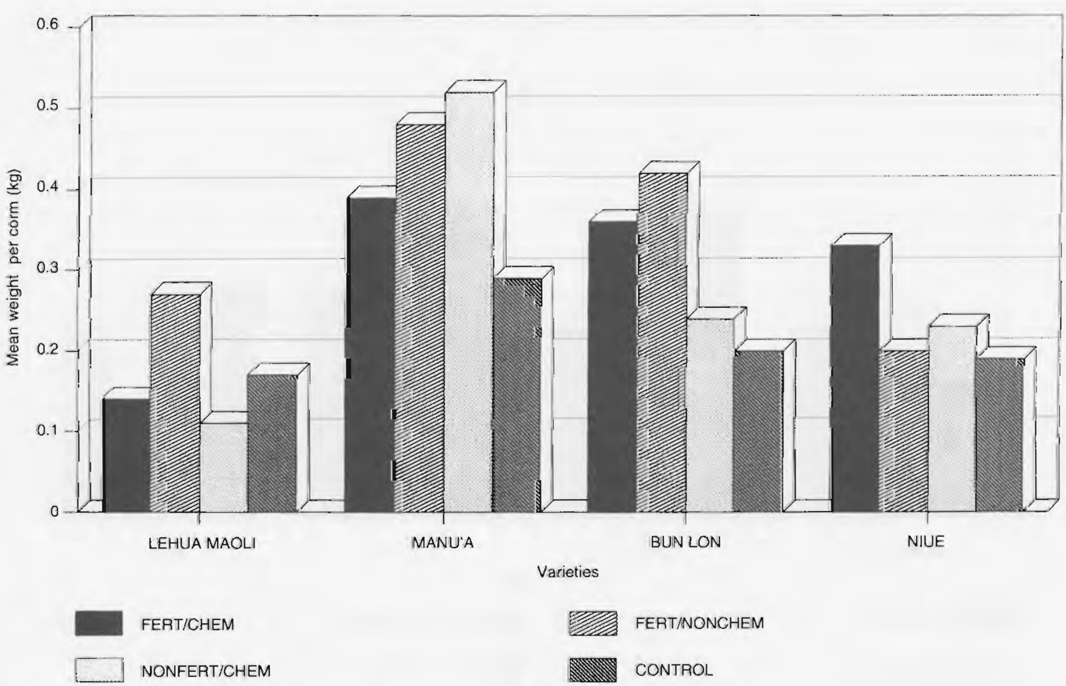

Fig. 4. Harvest corm weights of *Colocasia esculenta* with *Phytophthora colocasia* infection.

References

Berquist, R.R. 1972. Efficacy of fungicides for the control of *Phytophthora* leaf blight of taro. Annals of Botany 36, 281–287.

Bingham, F.T., Zentmyer, G.A. and Martin, J.P. 1958. Host nutrition in relation to *Phytophthora*. Phytopathology 48, 144–148.

Falcon, F., Fox, R.L., and Trujillo, E.E. 1984. Interactions of soil pH, nutrients and moisture on *Phytophthora* root rot of avocado. Plant and Soil 81, 165–176.

Greenough, D., Fa'aumu, S., and Tilialo, R. 1994. Effects of three concentrations of Ridomil 2E on the incidence of taro leaf blight (*Phytophthora colocasia*) on taro (*Colocasia esculenta*) in American Samoa. Phytopathology 84, 1115 (abstract).

Jackson, G.V.H. and Gollifer, D.E. 1975. Diseases and pest problems of taro (*Colocasia esculenta* [L.] Schott) in the British Solomon Islands. Pans 21, 45–53.

Lee, B.S. and Zentmyer, G.A. 1982. The influence of calcium nitrate and ammonium sulfate on *Phytophthora* root rot of *Persica indica*. Phytopathology 72, 1558–1564.

Silva, J. and Sato, D. 1993. Fertilizer recommendations for dryland-grown Chinese taro. The Taro Tattler 5, 3.

Strauss, M.S. 1984. Rabdovirus infection of taro, *Colocasia esculenta* (L.) Schott, from Papua New Guinea: comparison of symptomatic and asymptomatic material. In: Proceedings Sixth Symposium of the International Society Tropical Root Crops, Lima 1983. International Potato Center (CIP), 1984, 181–185.

Trujillo, E.E. and Aragaki, M. 1964. Taro blight and its control. Hawaii Farm Science 13, 11–13.

Trujillo, E.E. 1967. Diseases of the genus *Colocasia* in the Pacific area and their control. In: Tai, E.A., Charles, W.B., Iton, E.F., Haynes, P.H. and Leslie, K.A, ed., Proceedings International Symposium on Tropical Root Crops, University of the West Indies, Trinidad Vol. 2. (IV) 13–14.

Mineral Nutrition of Cassava

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Abstract

Although cassava (*Manihot esculenta* Crantz) is more productive than most other crops when grown on acid infertile soils, it is also very responsive to better soil fertility and may require high levels of fertilisation to reach its yield potential. In moderately acid soils, cassava generally does not respond to the application of lime except as a source of calcium and/or magnesium. High rates of liming often induce zinc deficiency. When grown on infertile soils cassava seldom shows clear symptoms of nitrogen, phosphorus or potassium deficiencies, but instead produces small and weak plants while root yields are reduced. Diagnosis of major nutrient deficiencies is best done through soil or plant tissue analysis.

The paper therefore describes both deficiency (or toxicity) symptoms as well as critical levels or ranges of each nutrient in soil and in cassava leaves. When grown on light textured and low organic matter soils, cassava tends to respond mainly to N application; however, due to the relatively large removal of K in the root harvest, continuous cassava cultivation on the same soil may lead to K exhaustion, and K will eventually become the most limiting nutrient. Under normal soil conditions cassava roots become readily infected with mycorrhizal fungi, which help the plant absorb P even at low external P concentrations in soil solution. Thus, in most cassava soils in Asia the crop does not respond much to P application.

BECAUSE cassava is well adapted to poor soils and is relatively tolerant of drought, the crop is usually grown under marginal soil and climatic conditions and often with very limited inputs of fertilizers and pesticides. Under these conditions cassava can still produce reasonably good yields where most other crops would fail. However, like any other crop, cassava only realises its high yield potential when it is supplied with adequate light, nutrients and water. Thus, when grown on infertile soils cassava responds well to the application of chemical fertilizers and manures or to the incorporation of green manures.

Symptoms of nutrition disorders in cassava, especially the deficiencies of nitrogen (N), phosphorus (P) and potassium (K), are often not readily recognised and farmers are unaware that their crop may be suffering from nutrition stresses leading to reduced yields. This makes the diagnosis of nutrition disorders rather difficult, and in some cases the diagnosis can be made only after soil and/or plant tissue analyses. For that reason, the most common symptoms of various nutrition disorders and critical levels for nutrition deficiencies or toxicities in the plant tissue (Table 1) and soil (Table 2) are given. The values can be used as a general guide for the interpretation of leaf or soil analysis results.

Since nutrient concentrations in the plant vary among the different tissues and change during the growth cycle, it is important to standardise the sampling of plant tissue for diagnosing nutrition disorders. It is recommended to sample the blades (without petioles) of youngest fully expanded leaves (YFEL) at 3–4 months after planting.

Soil Acidity and Aluminium Toxicity

Cassava is well adapted to acid soils because of its tolerance to high levels of aluminium (Al) in soil solution. However, in very acid soils with high levels of exchangeable Al and/or low levels of calcium (Ca), cassava can suffer from Al toxicity. This has been observed mainly in very acid Oxisols with a soil pH of 4.2–4.5 and an Al saturation of about 85%. However, in peat soils of Malaysia, with little

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exchangeable Al but high levels of exchange acidity, cassava produced very well in areas with a pH of 3.4, but showed severe nutrition disorders in areas with pH 3.1 and 6.5 cmol exchange acidity/kg.

Symptoms of Al toxicity are not very clear. In some varieties the lower leaves show interveinal yellowing and necrosis, but in most varieties there are few recognisable symptoms; plants are small and lack normal vigour. In nutrient solution culture with high concentrations of Al, cassava plants were found to be small with a short and stubby root system. Both Al toxicity and soil acidity stress can be prevented by the application of lime, which will decrease the Al saturation and raise soil pH. Rates of 0.5–2.0 t/ha of calcitic or dolomitic lime are generally required to obtain maximum yields in very acid mineral soils, while 3 t/ha of hydrated lime are required for maximum yield on peat soils. Higher rates of liming may result in the induction of micronutrient deficiencies (Spain et al. 1975).

Salinity and alkalinity

Cassava is seldom grown on saline alkaline soils because it is not well adapted to these conditions. The crop is rather sensitive to high pH and the associated problems of salinity, alkalinity and sometimes poor drainage. Moreover, at high pH there are often problems of micronutrient deficiencies, especially that of zinc (Zn).

Cassava plants suffering from salinity problems show a uniform yellowing of leaves, which starts at the top of the plant but quickly proceeds downward. Under moderate salinity stress the symptoms are similar to those of Fe deficiency. Under severe stress, the lower leaves become necrotic and fall off and plant growth is severely affected, sometimes leading to plant death.

Soil salinity can be improved by leaching out the salts through flooding and draining, while alkalinity can be reduced by the application of elemental sulfur (S) or gypsum; however, this is a long and expensive process. Since cassava varieties differ markedly in their tolerance to salinity problems it is more practical to select adapted varieties and apply micronutrients when necessary.

Nitrogen deficiency

Nitrogen deficiency is commonly observed when cassava is grown on light-textured soils with low organic matter content or in very acid soils with a low rate of N mineralisation. Nitrogen deficiency seems to be more common in Asia than in Latin America.

Some varieties show no symptoms of N deficiency, but plants remain small and weak while root yields are markedly reduced. Other varieties show clear symptoms of N deficiency: plants are uniformly chlorotic and leaves have a uniform light green or yellowish colour. Although N-deficiency symptoms first appear in the bottom leaves, they rapidly spread throughout the plant, leading to a generalised chlorosis. Nitrogen-deficient leaves are smaller and may have less lobes and shorter petioles than normal leaves.

The critical level for N deficiency in youngest fully-expanded leaf (YFEL) blades at 3–4 months after planting is about 5.3% N, while the sufficiency range is about 5.1–5.8% N (Table 1). (In this paper the critical level is defined as that concentration corresponding to 95% of maximum yield, while the sufficiency range is the concentration corresponding to 90–100% of maximum yield.)

To control N deficiency in cassava, an application of 50–100 kg N/ha in the form of urea or as a compound fertilizer during the first 2–3 months after planting is recommended. In light-textured soils, in which N may be lost through leaching, two applications are recommended, at planting and at 3 months. Nitrogen can also be applied in the form of animal manure (5–10 t/ha), or by the incorporation of or mulching with green manures or cover crops.

Phosphorus deficiency

Phosphorus deficiency is the most limiting nutrition factor for cassava grown on many acid infertile Oxisols, Ultisols and Inceptisols in Latin America, but it is less common in Asia. Phosphorus-deficient cassava plants are generally short and spindly with thin stems, small and narrow leaves and short petioles. During periods of drought the upper leaves tend to droop down from the petioles. The leaves are generally dark green while one or two lower leaves may be dark yellow to orange and in some varieties purplish with necrotic white spots. These lower leaves often drop off, leaving the plant without any recognisable symptoms.

The critical level for P deficiency in YFEL blades is about 0.41% P (Howeler and Cadavid, 1990) and the sufficiency range is calculated to be 0.38–0.50% P (Table 1). The critical level of available P in the soil is about 4–6 µg/g Bray II-extractable P (Howeler 1990). In some soils having only 2–4 µg/g available P there is still no response to P application due to a highly efficient mycorrhizal association (Howeler et al. 1987), which enables the plant to absorb soil P from a greater soil volume.

To control P deficiency it is recommended to band-apply near the stake 25–50 kg P/ha as highly soluble P-sources such as single or triple superphosphate or compound fertilizers; alternatively, P can be applied by broadcasting and incorporating less soluble sources such as basic slag, rock phosphate or thermophosphate. The latter are good sources of P in acid soils. All P should be applied at or shortly after planting to enhance early growth and plant vigour.

Potassium deficiency

Cassava extracts large amounts of K in the root harvest and long-term fertility trials have shown that sooner or later K deficiency becomes the most limiting nutrition factor if it is grown continuously without adequate K fertilisation.

Potassium-deficient plants are generally short, highly branched and with a prostrate growth habit. In many varieties the upper internodes are very short and prematurely lignified resulting in a 'zigzagging' of the upper stem. In some varieties, the upper leaves are small and chlorotic, while in others a few lower leaves are yellow with black spots and border necrosis. During periods of drought leaf borders may curl upward, while during wet periods there may be severe die-back of shoot tips due to K deficiency-induced anthracnose (*Colletotrichum* spp.). In many cases, however, there are no clearly recognisable symptoms and plants are simply shorter and have smaller leaves than those well supplied with K.

The critical level for K deficiency in YFEL blades at 3–4 months after planting is about 1.5% K, while the sufficiency range is 1.4–1.9% K (Table 1). The critical level of exchangeable K in the soil was found to be 0.15–0.17 cmol/kg (Howeler 1985a; Howeler and Cadavid 1990).

Potassium deficiency in cassava can be controlled by the application of 50–100 kg K/ha as potassium chloride. Potassium can also be applied as a compound fertilizer or in the form of wood ash. In soils where P deficiency is not a serious problem, compound fertilizers with an N-P_2O_5-K_2O ratio of about 2:1:3 or 2:1:4 are recommended in order to supply enough K to prevent K exhaustion of the soil. Most K fertilizers are highly soluble and should be band-applied near the stake during the first two months after planting. In light-textured soils they should be applied in two smaller doses to prevent losses by leaching.

Calcium deficiency

Calcium deficiency symptoms are easily produced in nutrient solution culture, but are seldom seen in the field; significant responses of cassava to Ca application are also rather rare. Still, in very acid soils with high levels of Al and low levels of Ca, cassava does respond to liming, which is thought to be mainly a response to the application of Ca and/or magnesium (Mg).

Since Ca is not very mobile in the phloem, there is little Ca translocation from the older to the younger tissue. When the Ca supply is inadequate, symptoms of Ca deficiency develop in the growing points of both shoots and roots. Upper leaves are deformed with leaf tips burned and curling either up or down. The growing points of fibrous roots die back, resulting in excessive root branching. In the field, Ca deficiency is characterised mainly by deformation and burning of leaf tips in the upper part of the plant, but these symptoms cannot be seen in all varieties.

The critical concentration for Ca deficiency in YFEL blades at 3–4 months after planting was found to be 0.56% Ca and the sufficiency range calculated to be about 0.50–0.72% Ca (Table 1). However, Ca concentrations in YFEL blades can vary markedly among different varieties.

Calcium deficiency is generally controlled by the application of 200–400 kg Ca/ha in the form of calcitic or dolomitic limestone, as calcium oxide or hydroxide, or as gypsum. Gypsum is a more soluble source, which supplies Ca as a nutrient but without affecting soil pH or exchangeable Al. All these Ca sources should be broadcast and incorporated before planting.

Magnesium deficiency

Magnesium deficiency symptoms are often found in acid infertile soils such as Oxisols, Ultisols and certain Inceptisols.

Magnesium deficiency is characterised by interveinal chlorosis of the lower leaves, which starts out as slight yellowing of leaf margins and may eventually develop into necrosis of leaf tips and margins. Symptoms appear first at the lowest leaves and progressively move up the plant.

Critical concentrations for Mg deficiency in YFEL blades at 3–4 months after planting were found to be 0.25% Mg and the sufficiency range was calculated as 0.24–0.29% Mg (Table 1). No critical levels for soil exchangeable Mg have been reported, but Mg deficiency symptoms and a response to Mg application were found in soils with less than 0.2 m-equiv. Mg/kg (Table 2).

Magnesium deficiency can be controlled by the application of 40–60 kg Mg/ha in the form of magnesium oxide, dolomitic limestone or magnesium sulphate. The first two sources are relatively insoluble and should be broadcast and incorporated before planting. Magnesium sulphate is a soluble source, which may be band-applied near the stake shortly after planting. It has no effect on soil pH or exchangeable Al, but can be used as a source of S.

Sulfur deficiency

Sulfur deficiency in cassava is easily produced in nutrient solutions, but is not often found in the field.

Table 1. Nutrient concentrations in youngest fully-expanded leaf blades of cassava at 3–4 months after planting, corresponding to various nutrition states of the plants. Data are the average results of various greenhouse and field trials.

Nutrient	Nutritional states[a]					
	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1–4.8	4.8–5.1	5.1–5.8	>5.8	[b]
P (%)	<0.25	0.25–0.36	0.36–0.38	0.38–0.50	>0.50	—
K (%)	<0.85	0.85–1.26	1.26–1.42	1.42–1.88	1.88–2.40	>2.40
Ca (%)	<0.25	0.25–0.41	0.41–0.50	0.50–0.72	0.72–0.88	>0.88
Mg (%)	<0.15	0.15–0.22	0.22–0.24	0.24–0.29	>0.29	—
S (%)	<0.20	0.20–0.27	0.27–0.30	0.30–0.36	>0.36	—
B (μg/g)	<7	7–15	15–18	18–28	28–64	>64
Cu (μg/g)	<1.5	1.5–4.8	4.8–6.0	6–10	10–15	>15
Fe (μg/g)	<100	100–110	110–120	120–140	140–200	>200
Mn (μg/g)	<30	30–40	40–50	50–150	150–250	>250
Zn (μg/g)	<25	25–32	32–35	35–57	57–120	>120

[a] Very deficient = <40% maximum yield
Deficient = 40–80% " "
Low = 80–90% " "
Sufficient = 90–100% " "
High = 100–90% " "
Toxic = <90% " "

[b] — = no data available.

Table 2. Approximate classification of soil chemical characteristics according to the nutrition requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH	<3.5	3.5–4.5	4.5–7	7–8	>8
Org. matter	<1.0	1.0–2.0	2.0–4.0	>4.0	
Al-saturation (%)			<75	75–85	>85
Salinity (mS/cm)			<0.5	0.5–1.0	>1.0
Na-saturation (%)			<2	2–10	>10
P (μg/g)	<2	2–4	4–15	>15	
K (me/100g)	<0.10	0.10–0.15	0.15–0.25	>0.25	
Ca (me/100g)	<0.25	0.25–1.0	1.0–5.0	>5.0	
Mg (me/100g)	<0.2	0.2–0.4	0.4–1.0	>1.0	
S (μg/g)	<20	20–40	40–70	>70	
B (μg/g)	<0.2	0.2–0.5	0.5–1.0	1–2	>2
Cu (μg/g)	<0.1	0.1–0.3	0.3–1.0	1–5	>5
Mn (μg/g)	<5	5–10	10–100	100–250	>250
Fe (μg/g)	<1	1–10	10–100	>100	
Zn (μg/g)	<0.5	0.5–1.0	1.0–5.0	5–50	>50

pH in H_2O; OM by method of Walkley and Black;
Al-saturation = 100 × Al/(Al+Ca+Mg+K) in cmol/kg;
P in Bray II; K, Ca, Mg and Na in 1N NH_4-acetate; S in Ca-phosphate
B in hot water; and Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

It is characterised by a uniform chlorosis or yellowing of leaves (similar to N deficiency) in the upper and middle part of the plant. Eventually the whole plant becomes chlorotic. Leaves are small and plant height may be reduced, but leaves are not deformed.

The critical concentration for S deficiency in YFEL blades was found to be about 0.31% S, while the sufficiency range was calculated to be 0.30–0.36% S (Table 1). Critical levels in the soil have not been determined, but S responses were obtained in soils with 25–30 µg/g phosphate-extractable S.

Sulfur deficiency can be controlled by the application of 10–20 kg S/ha as elemental sulfur or as sulfates of ammonium, potassium, calcium or magnesium. The latter four sources are relatively soluble and can be band-applied near the stake at planting, while elemental sulfur should be broadcast and incorporated before planting.

Boron deficiency and toxicity

Symptoms of boron (B) deficiency are not commonly observed in the field, but are easily produced in nutrient solution. Since B is a phloem-immobile element, deficiency symptoms are mainly found in the growing points of shoots and roots. Thus extremely B-deficient plants have small and deformed leaves in the upper part of the plant with, in some cases, exudation of a brown gummy substance from the upper petioles. Root tips often die, resulting in a small and excessively branched root system (Asher et al. 1980). In the field these symptoms are seldom observed. Boron deficiency in the field is generally characterised by white or brown speckles on leaves in the middle part of the plant. Some varieties are much more susceptible than others, but in general cassava is quite tolerant of low levels of available B in the soil.

Symptoms of B toxicity have been found only when B was applied at too high rates. In that case, lower leaves are deformed with yellow or brown spots and necrosis of leaf tips and margins. Since B is not translocated to the growing points, plants generally recuperate from an initial B toxicity.

The critical concentration for B deficiency in YFEL blades, as determined in two nutrient solution experiments, were found to be 21 and 35 µg B/g, while those for B toxicity were 50 and 100 µg B/g (Howeler et al. 1982; J.M. Portieles, pers. comm.). However, B concentrations of less than 10 µg B/g were found in YFEL blades of apparently normal field-grown plants. A sufficiency range was calculated to be about 18–28 µg B/g (Table 1). Symptoms of B deficiency and some response to B application have been found in soils with 0.2–0.3 µg/g of hot water-soluble B. A normal range of B in the soil is about 0.5–1.0 µg/g (Table 2).

Boron deficiency can be controlled by the application of 1–2 kg B/ha in the form of sodium borates, such as Borax or Solubor. These sources are rather soluble and can be band-applied near the stake at planting. Alternatively, stakes can be dipped in a solution of 1% Borax before planting; however, concentrations above 1% may result in B toxicity.

Copper deficiency

Symptoms of Cu deficiency in cassava have been produced in nutrient solution culture but are seldom seen in the field. Severe symptoms and yield reductions due to Cu deficiency were found only on the peat soils of Malaysia, where high levels of organic matter result in the complexing of Cu with humic acids, making the Cu unavailable to plants.

Copper deficiency in cassava is characterised by chlorosis, deformation and wrinkling of upper leaves with necrosis of leaf tips and margins; leaf tips curl either up or down. Leaves in the middle and lower part of the plant are rather large and suspended on long and bent-down petioles.

A critical concentration for Cu deficiency in YFEL blades after 9 weeks of growth in nutrient solution was reported to be 6 µg/g, while that for Cu toxicity was about 15 µg/g (Howeler et al. 1982). The sufficiency range was calculated to be about 6–10 µg Cu/g (Table 1). However, high yields on peat soils in Malaysia were obtained with Cu concentrations of 14–15 µg Cu/g in YFEL blades (Chew et al. 1978). Critical levels of available Cu in the soil have not been determined, but about 0.3–1.0 µg/g double-acid extractable Cu is considered a normal range for cassava (Table 2).

Copper deficiency can be controlled with the application of 2.5-3.5 kg Cu/ha as $CuSO_4.5H_2O$, band-applied near the stake at planting. Copper deficiency can also be controlled by foliar application of 0.05% $CuSO_4.5H_2O$; higher concentrations resulted in reduced yields (Chan and Ramli, 1987).

Manganese deficiency and toxicity

Manganese (Mn) deficiency is found mainly in high pH calcareous soils or in acid soils treated with excessive amounts of lime. Its symptoms are similar to those of Mg deficiency, but are found mainly in the middle part of the plant. Manganese-deficient plants have leaves with interveinal chlorosis, in which the green veins stand out in a 'fishbone' pattern on a yellow background. Under severe conditions the whole leaf may turn almost uniformly yellow (similar to Fe deficiency), while plant height is reduced. Leaves usually maintain their normal size and are not deformed.

Manganese toxicity is usually found in very acid soils, especially under conditions of excess water resulting in the reduction of higher oxides of Mn to the more soluble Mn^{2+} form.

However, Mn toxicity may also occur during the dry season when stagnated growth can lead to excessive accumulation of Mn in the lower leaves. It is characterised by brown or black speckling along the veins of lower leaves. These leaves are initially green, but later turn yellow to orange. They may be hanging flaccid on the petioles before they fall off. Manganese toxicity may also severely reduce root growth.

The critical concentration for Mn deficiency in YFEL blades was found to be about 50 µg Mn/g, while that for Mn toxicity was about 250 µg Mn/g (Howeler et al. 1982). The sufficiency range was estimated at 50–150 µg Mn/g. Critical levels of available Mn in the soil have not been determined, but about 10–100 µg/g of double-acid extractable Mn may be considered a normal range for cassava (Table 2).

Manganese deficiency can be corrected by soil application of manganese oxide or sulfate, by a foliar spray with Mn chelates or a 1–2% solution of $MnSO_4.4H_2O$, or by dipping the stakes in a 5% solution of $MnSO_4.4H_2O$ for 15 minutes before planting. Manganese toxicity can be controlled by the application of lime in acid soil and by providing better internal drainage by loosening compacted soil.

Iron deficiency

Iron (Fe) deficiency is quite common when cassava is grown on calcareous soils. It has also been observed when cassava is grown on levelled-off termite hills; these soils have high concentrations of Ca, Mg and K and an elevated soil pH. Iron deficiency can also be induced by high applications of lime and/or P in acid sandy soils of low Fe content, as well as by excessive absorption of Mn.

Iron-deficient plants have a uniform chlorosis of the upper leaves including the veins. Under severe conditions the upper leaves may turn completely white, while lower leaves become increasingly chlorotic. Plant height may be reduced and seriously affected plants may die. Symptoms of Fe deficiency are most serious during the dry season and may completely disappear again during the following wet season.

The critical concentration for Fe deficiency in YFEL blades could not be clearly established (Howeler et al. 1982), but a sufficiency range was estimated to be 120–140 µg Fe/g (Howeler 1983). Concentrations of over 400 µg/g may result in a reduction in plant growth, but no symptoms of Fe toxicity nor a reduction in root yield have been observed. Critical levels of available Fe in the soil have not been determined, but about 10–100 µg Fe/g is a normal range for cassava (Table 2).

Iron deficiency is best controlled by a foliar spray of iron chelates or a 1–2% solution of $FeSO_4.7H_2O$. Dipping stakes in a solution of 5% $FeSO_4.7H_2O$ for 15 minutes before planting had no adverse affect on germination, but its effectiveness in controlling Fe deficiency still needs to be determined.

Zinc deficiency

Zinc deficiency is a rather common nutrition disorder in cassava and is observed both in high pH soils, due to a reduced availability of Zn, and in low pH soils, due to their low levels of total Zn.

In cassava it is characterised by white speckling or striping in the interveinal region of upper leaves. These leaves may become chlorotic, they are usually small in size and have narrow leaf lobes which tend to point away from the petiole and stem. Under more severe conditions the leaves in the growing point become increasingly chlorotic and deformed, while in some varieties the lower leaves have white necrotic spots or generalised chorosis in the interveinal areas. Zinc deficiency is often observed when plants are young, but they may grow out of it once the root system is better developed. Under severe Zn deficiency stress, shoot tips die back or the whole plant may die.

The critical concentration for Zn deficiency in YFEL blades was found to be 40 µg Zn/g, while the sufficiency range was calculated to be 35–57 µg Zn/g. A critical level for soil-available Zn has been reported as 1 µg/g of double-acid extractable Zn (Howeler 1985b); a Zn level of 1–5 µg/g can be considered as a normal range for cassava (Table 2).

Zinc deficiency can be controlled by band-application of 5–10 kg Zn/ha as $ZnSO_4.7H_2O$ or by broadcast-application of 10–20 kg Zn/ha as ZnO. In high pH soils, in which applied Zn soon becomes unavailable to plants, it is more effective to make foliar applications of 1–2% solutions of $ZnSO_4.7H_2O$ or to dip stakes for 15 minutes in a solution of 2–4% $ZnSO_4.7H_2O$ before planting. The latter is a very cheap and effective method of preventing serious Zn deficiency in alkaline or calcareous soils (CIAT 1985).

References

Asher, C.J., Edwards, D.G. and Howeler, R.H. 1980. Nutritional Disorders of Cassava. Department of Agriculture, University of Queensland, St Lucia, Qld, Australia. 48 p.

Centro Internacional de Agricultura Tropical (CIAT). 1985. CIAT Annual Report for 1982 and 1983. Cassava Program, Cali, Colombia.

Chan, S.K. and Ramli, K. 1987. Evaluation of three methods of copper fertilization for cassava on peat. In: Lim, K.H. and Talib, J., ed., Recent Advances on Soil and Water Management in Malaysian Agriculture, Proceedings National Seminar, Kuala Lumpur, Malaysia, March 20, 1986. 69–78.

Chew, W.Y., Joseph, K.T. and Ramli, K. 1978. Influence of soil-applied micronutrients on cassava (*Manihot esculenta*) in Malaysian tropical oligotrophic peat. Experimental Agriculture, 14. 105–111.

Howeler, R.H. 1983. Analisis del tejido vegetal en el diagnostico de problemas nutricionales de algunos cultivos tropicales. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 28 p.

— 1985a. Potassium nutrition of cassava. In: Potassium in Agriculture. International Symposium held in Atlanta, Ga, USA, July 7–10, 1985. ASA, CSSA, SSSA, Madison, Wisc., USA. 819–842.

— 1985b. Mineral nutrition and fertilisation of cassava. In. Cassava: Research, Production and Utilization. UNDP-CIAT Cassava Program. Cali, Colombia. 249–320.

— 1990. Phosphorus requirements and management of tropical root and tuber crops. In: Proceedings Symposium on Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania. IRRI, Los Banos, Philippines, March 6–10, 1989. 427–444.

Howeler, R.H. and Cadavid, L.F. 1990. Short- and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Research, 26. 61–80.

Howeler, R.H., Edwards D.G. and Asher, C.J. 1982. Micronutrient deficiencies and toxicities of cassava plants grown in nutrient solutions. I. Critical tissue concentrations. Journal of Plant Nutrition 5. 1059–1076.

Howeler, R.H., Sieverding, E. and Saif, S. 1987. Practical aspects of mycorrhizal technology in some tropical crops and pastures. Plant and Soil, 100. 249–283.

Spain, J.M., Francis, C.A., Howeler, R.H. and Calvo, F. 1975. Differential species and varietal tolerance to soil acidity in tropical crops and pastures. In: Bornemisza, E. and Alvarado, A., ed., Soil Management in Tropical America. North Carolina State University, Raleigh, NC, USA. 308–329.

Mineral Nutrition of Root Crops in Fiji

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Abstract

Root crops, in particular ginger, taro and sweet potato, have a place in commercial and smallholder Fijian agriculture, and they fit readily into crop rotations involving other vegetables. As population pressure in the Fiji Islands and elsewhere increases, root crops may assume a more significant role in both local and export markets due to their ease of cultivation, short growth duration habits, high yields, and good eating and keeping qualities. Opportunities exist to study these and other root crops in both commercial and smallholder farming systems. An understanding of their mineral nutrition and the ability to cost-effectively diagnose any nutrition limitations (by soil test, foliar analysis or pictorial representation) will be vital as Fiji aims for greater export earnings, greater acceptance of a wider variety of root crops on local markets and more sustainable agricultural production in the future.

ROOT crops in Fiji, although of less economic importance than sugar, remain the staple diet of about half Fiji's population. In 1993, sugar alone accounted for 41% of total agricultural GDP in Fiji, whereas all other crops including root crops accounted for 14%. The main root crops are ginger, cassava, taro (dalo), sweet potato and yams. Root crops are generally grown by semi-subsistence farmers principally for their own use, although there are significant commercial plantings of ginger and Samoan Pink taro for export plus local Fijian varieties of taro for local markets. Ginger and taro are the next most important export crops after sugar ($F300–400 million annually), each valued at $F4–6 million annually ($F1.00 = $A1.046 approx.), and with expanding export markets. The major production areas for ginger, taro and sweet potato in Fiji are shown in Figure 1.

Research is currently being conducted by Fiji's Ministry of Agriculture, Fisheries and Forests (MAFF) on root crops in the following areas: (1) ginger nutrition and management; (2) taro for early maturing, drought-tolerant and high-yielding varieties; (3) sweet potato for scab and weevil resistant varieties; and (4) cassava and yams for high yielding varieties. Although the mineral nutrition of root crops has been little studied in the past, MAFF recognises the importance of understanding their nutrition requirements if production levels and quality are to be improved through the adoption of better varieties. This paper provides an overview of production systems, soils and their limitations, and the current direction of mineral nutrition research in Fiji on ginger, taro and sweet potato.

Ginger

Ginger was introduced to Fiji a century ago as a spice crop. Today, it is an important export crop marketed in immature unprocessed, or immature processed (crystallised ginger) forms or as a fresh mature vegetable. Immature ginger is processed in Fiji and sold in New Zealand, the United Kingdom, Germany and Australia. Fiji also exports over $F2 million worth of immature and mature fresh ginger to North America including Los Angeles, San Francisco, Seattle and Vancouver. An industry-based Ginger Growers Council of Fiji was established in 1993 specifically to support growers, exporters and others involved in Fiji's ginger export industry.

Ginger Production

Ginger is grown mainly in the south-eastern provinces of Viti Levu, along the Rewa River (Davuilevu, Naisoqo and Waibau areas), Navua and

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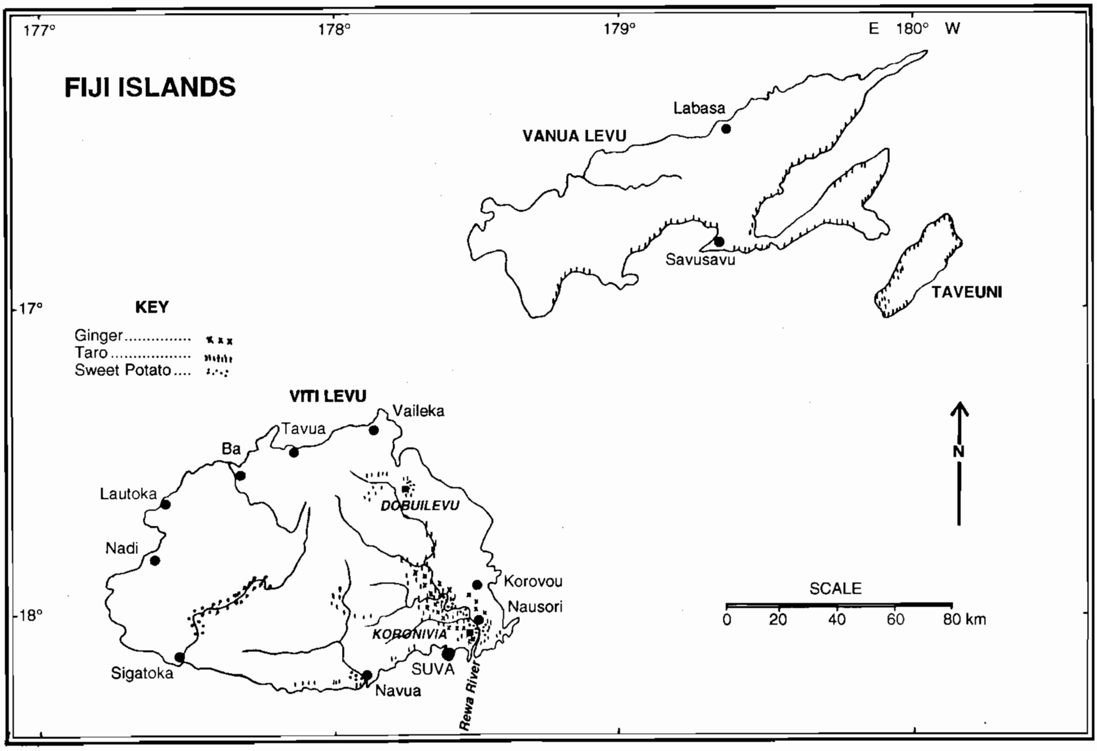

Fig. 1. Ginger, taro and sweet potato growing areas in Fiji.

Tailevu, areas of suitable climate with annual rainfall more than 3000 mm. Sloping lands, possibly prone to erosion, are preferred to flatter lands to minimise disease risks. On sloping lands, natural vegetation is removed and the land prepared using digging forks. Shallow furrows are made for planting down the slope to allow drainage. Land preparation is costly and laborious. As the area and production of ginger in Fiji are increasing and there is potential for increasing erosion on sloping lands, research on the mechanised cultivation of ginger on flat lands using raised beds to facilitate drainage is being undertaken.

Due to nematode and disease problems, ginger is usually planted on newly cleared land. Failing this, a four year rotation of ginger-taro-cassava-fallow-ginger is recommended. Immature ginger is harvested at 5-6 months and mature ginger at 10 months. Soil conservation measures (e.g. contour planting) are not usually applied. Weeds are usually controlled chemically. Farmers can modify this rotation by planting vegetables or sweet potato during the fallow period, and the use of both organic and inorganic fertilizers can be high. This rotation has helped reduce pests and diseases, minimise tillage operation, maintain soil fertility and increase production of taro and cassava, and allow better utilisation of available on-farm resources.

Likely Soil Limitations

Ginger requires well-drained, deep loamy soils. Newly cleared lands with high amounts of organic matter and a gentle slope are most suitable. Ginger is grown mainly on Humic Latosols, particularly on hilly areas of Waidina clay, Waimaro clay, Sote clay and Lobau clay. It is also grown on nigrescent soils, particularly Samabula clay and Wailoku clay on the Suva Peninsula. According to some farmers, ginger performs better on these 'darker', neutral to alkaline soils than on 'redder', more acidic soils. But yields on darker soils tend to decline rapidly over time. Consistently high yields can be obtained on red soils with adequate fertilisation and good management. Lime can be used to correct acidity problems.

From a series of fertilizer trials during the early 1980s, fertilizers are typically recommended for both immature and mature ginger as follows: (1) poultry manure (10 t/ha) applied during land preparation to help control root-knot nematodes; (2) N–P–K (13:31:21) mix at 1 t/ha, half at planting and half three months after planting; and (3) urea (300 kg/ha) in three split applications for immature ginger and four applications for mature ginger. Leaf samples taken from farmers' fields suggest few limitations (Table 1) except occasionally for N, P and Ca deficiencies. Low levels of Ca uptake are a concern, given the high rates of K fertilizer applied and a possible cation (Ca to K ratio) imbalance. Cation imbalances due to use of mixed N–P–K fertilizers containing very high K levels may be occurring. In the Sigatoka area, for example, high K fertilizers are often used and blossom end rot is common in tomatoes. Ca deficiency is suggested but soil Ca levels are high (Table 2). Hence the problem may lie in the oversupply of K.

Directions of Research on Ginger

As part of the Farming System Research and Development (FSRD) approach to the ginger industry initiated in 1994, an exploratory Rapid Rural Appraisal (RRA) was conducted, and farmers' problems identified and research devised to solve these problems. For example, soil analyses suggested most farms had soil pH levels of 4.1–5.6 and low P availability (Olsen-P levels of 8–10 mg/kg). As a result, ginger trials at nine sites (treatments: control; lime; P; and lime+P) were planted in September 1994. Observations suggest the combined lime+P treatment was out-performing those receiving lime or P alone. Another trial was planted at Koronivia Research Station to describe ginger responses to 100–400 kg/ha N, 150 and 250 kg/ha K, and 0 and 10 t/ha poultry manure on a Fluventic Eutropept

Table 1. Foliar analyses for ginger, taro and sweet potato growing areas in Fiji.

Area		N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
				(%)					(mg/kg)		
Ginger											
Davuilevu	Mean	3.66	0.31	3.71	0.43	0.47	210	506	10	33	nd
(n=5)	CV%	8	10	7	5	9	9	47	30	6	
Naisoqo	Mean	3.44	0.38	3.80	0.47	0.42	261	949	16	40	nd
(n=5)	CV%	6	5	7	11	10	44	22	25	32	
Waibau	Mean	3.47	0.44	4.12	0.40	0.44	169	375	14	35	nd
(n=4)	CV%	4	9	12	20	14	5	23	36	23	
Taro											
Nausori	Mean	3.26	0.36	3.05	1.31	0.42	nd	nd	nd	nd	nd
(n=17)	CV%	30	4	8	9	5					
Sweet potato											
Baulevu	Mean	2.35	0.32	4.03	0.84	0.44	696	47	11	19	34
(n=9)	CV%	20	22	22	31	22	67	40	30	20	15
Sigatoka	Mean	2.28	0.29	3.27	1.56	0.50	164	45	20	19	35
(n=5)	CV%	14	32	28	39	19	32	31	51	13	20

nd: not determined

Table 2. Soil analytical data for taro and sweet potato growing areas in Fiji.

Area		pH	Olsen-P (mg/kg)	Ca	Mg	K	Na	B (mg/kg)
					(cmol (+)/kg)			
Taro								
Nausori	Mean	5.9	5	16	6.6	0.54	nd	nd
(n=6)	CV%	6	28	13	12	4		
Sweet potato								
Baulevu	Mean	6.3	10	14	5.3	0.49	0.20	0.2
(n=13)	CV%	5	34	22	30	56	20	87
Sigatoka	Mean	6.2	13	12	4.0	0.66	0.17	nd
(n=4)	CV%	9	58	91	58	72	56	

nd: not determined

(Rewa soil series). Soil analysis indicated 8–10 mg/kg Olsen-P and 0.25–0.40 (cmol(+)/kg) exchange K. Best growth was observed in treatments receiving higher rates of N only.

Also at the International Board for Soil Research and Management (IBSRAM) PACIFICLAND site in Fiji, MAFF is involved in determining rates of soil loss and land degradation under the recommended ginger-taro-cassava-fallow rotation with the inclusion of pineapple or vetiver grass on the contour. This study aims to develop improved technologies and farming systems to enable farmers to better manage their sloping lands. Data from 1991–92 suggest less soil loss from areas under ginger with vetiver or pineapple planted along the contour. With better land management and less erosion, downstream effects of siltation and flooding should be less severe.

As ginger is an important export crop, MAFF has recognised the need to develop farmer-driven and problem-driven research programs to improve ginger production in Fiji. Areas targeted include: (1) pest and disease management; (2) development of more effective farming systems involving using raised beds on flat lands and more appropriate conservation practices on sloping lands; and (3) identification and correction of nutrient deficiencies.

Taro (dalo)

Taro has long been grown in Fiji as a staple food crop. Socially, it is important and its presentation, with yam, is often essential at traditional functions. In local markets, taro is often preferred to cassava as its leaves can be used as a green vegetable ('rourou'). Recently, demand for taro varieties with characteristics similar to Tausalsa ni Samoa (Samoan Pink) for export has increased. Export earnings in 1994 were A$5.27 million. Sales on export and local markets make taro an important source of income to many farmers.

Taro production

In Fiji, taro is grown in wet and intermediate rainfall (>2500 mm) zones. The main growing areas are on the island of Viti Levu in the Rewa Delta area, in Ra Province near Vaileka, in Cakaudrove Province on Vanua Levu in Taveuni, and in the outer eastern islands. Taro is typically grown under rain-fed conditions on either flat or sloping lands. Fijian varieties including Samoan hybrid are grown mainly on older volcanic soils in eastern Viti Levu for local markets. Samoan Pink taro is grown mainly on younger volcanic soils in Taveuni and other eastern islands.

Traditionally, taro is planted manually in a hole made in the ground using a stick or narrow spade. Organic manures are occasionally used. Inorganic fertilizers are seldom applied. In some cases, chemicals are used for weed control. Mechanised and semi-mechanised methods may be used on flat lands with taro planted in furrows. Land preparation, furrow-making, and later tillage operations are carried out by animal- or tractor-drawn implements. Traditional methods are more costly than mechanised or semi-mechanised systems. Also, there is little difference in corm yield in manual relative to mechanised systems. Further, taro is grown under a variety of farming systems. In subsistence and semi-subsistence systems, it is grown for food, with any surplus sold locally. Soil fertility is maintained through the practice of shifting cultivation, and a number of taro varieties are typically grown together to ensure continuous production. Other vegetables may be intercropped with it.

Taro can also be grown as a cash crop, and different farming systems have been adopted for sloping and flat lands. On sloping lands, it may be rotated with high-value crops such as ginger, but labour inputs for land preparation, planting and weeding are high since mechanisation isx often not feasible. A single taro variety is usually grown and often fertilizer is used. However, on flat lands, fertilizers and mechanisation are commonly used and the normal practice is to grow a single taro variety with a ready market.

Likely soil limitations

During the 1970s, a series of N–P–K trials was conducted and responses to N and P recorded. Current N-P-K recommendations are: (1) 100 kg/ha N plus 25 kg/ha P and/or 100 kg/ha K (if P and /or K levels are low), or (2) in the absence of soil analysis, 400 kg/ha NPK (13:13:21) plus 50 kg/ha N. Poultry manure at 10 t/ha is also used. MAFF is currently undertaking NPK trials to reassess fertilizer requirements of taro. Recent soil and foliar analyses from the Nausori area (Koronivia Research Station) suggest few limitations except for P where Olsen-P levels were low (Tables 1 and 2). As mentioned earlier, consideration should also be given to a possible cation (Ca/K) imbalance when using the high K fertilizer mix in soils with high K levels.

Research directions

Current research focuses on developing taro varieties with characteristics similar to Samoan Pink, and improving drought, pest, and disease tolerance, corm quality, and yield. Government policy focuses on export-led growth in taro production. A taro germplasm collection is maintained at Koronivia Research Station.

Taro is best suited to poorly drained soils. With the decline of the rice industry, many 'rice-growing' soils with minor amelioration may be suitable for taro. MAFF is currently considering management options for these soils.

Sweet Potato

Sweet potato is produced largely for on-farm consumption. Over the past five years, pests and diseases, high transportation costs and low market prices have led to an annual decline in production per farmer from 1.2 (1990) to 0.6 t (1994), but the number of farmers growing sweet potato has increased from 2514 to 7100 over the same period.

Although sweet potato is consumed by a majority of Fiji's people, very few plant nutrition studies been completed or published. There were some inconclusive fertilizer trials at Koronivia during 1949 and 1950, but yields were generally low (relative to local averages) and treatment effects were not significant. Most research work to date has concentrated on developing sweet potato varieties with resistance to scab and weevil attack. Currently, MAFF is not undertaking studies on the mineral nutrition of sweet potato.

Sweet potato production

Sweet potato is grown commercially along the Baulevu, Nasi, and Muaniweni alluvial flats of the Rewa River on Fluventic Eutropept soils, and in the Sigatoka valley on mainly Ustic Humitropept and Cumulic Haplustull soils. Elsewhere, it is grown mainly for subsistence purposes and not on a large scale. Sweet potato is typically grown in rotation with legumes and other vegetables. Vines are planted on ridges, fertilizer is rarely used, and little or no weeding occurs during the growing season. Commercial tuber yields are typically 10–15 t/ha in the Sigatoka area and 7–8 t/ha in the Baulevu area.

Likely soil limitations

For the major commercial sweet potato producing areas of Baulevu and Sigatoka, soil and foliar samples were collected on farms growing sweet potatoes during January 1995. Data are summarised in Tables 1 and 2. Except for low levels of available soil P (Olsen-P) and low foliar N, which may act to limit sweet potato growth in the field, the nutrition status of these soils appears adequate for reasonable growth. However, symptoms of B (boron) deficiency have been observed on paw paw grown under low rainfall in the Sigatoka area. Also, P deficiency is suggested by soil analysis but not supported by foliar data, suggesting another factor, e.g. VAM fungi, may be acting to enhance P uptake in these soils.

Review of Some Fertilizer Research on Root and Tuber Crops and Farmer Adaptive Strategies to the Short Fallow Systems in Lowland Papua New Guinea

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Abstract

In Papua New Guinea (PNG) while rice continues to assume greater significance as a staple food within rural communities, root and tuber crops are still important staples. The root and tuber crops grown are sweet potato (*Ipomoea batatas*), lesser yam (*Dioscorea esculenta*), greater yam (*Dioscorea alata*), taro (*Colocasia esculenta*) and Chinese taro (*Xanthosoma sagittifolium*), cassava (*Manihot esculenta*) and, to a lesser extent, giant taro and swamp taro.

Root and tuber crops in lowland PNG are still primarily produced by subsistence farmers under the traditional method of shifting cultivation. In the past this traditional system of cultivation with its long forest fallow (more than 15 years), could reliably sustain soil fertility lost through leaching, erosion and gardening. In the latter half of this century, however, in many lowland areas of the country, there has been a rapid shift away from the long forest fallow system toward a more sedentary and unstable short bush and grass fallow system. This change has come about due to a shortage of land caused by population pressure and in some areas the allocation of good arable land to plantation crops. The short fallow system with almost continuous cultivation of crops and meagre restorative measures has resulted in declining yields corresponding to declining soil fertility. This paper briefly discusses results of some fertilizer research conducted in lowland PNG and some adaptive strategies that have been adopted by subsistence farmers in response to declining food crop yields.

THE PNG lowlands include regions of the country that are within 0–500 metres above sea level. There are two distinct climatic environments, the wet lowlands, which represent the major environment, and the seasonally dry lowlands which represent only a small proportion of the region. Annual rainfall in the wet lowlands is over 2000 mm and fairly well distributed. In the seasonally dry lowlands, rainfall is 1000–2000 mm annually. Soil water deficits occur for at least four months of the year in the seasonally dry areas.

The vegetation is tropical forests in the wet lowlands and man-induced grasslands and savanna in the seasonally dry areas. Temperatures in the lowlands are constantly high with mean minimum and maximum readings of 28–34°C and 20–25°C, respectively, with a daily fluctuation of about 7°C (Bourke and Bull 1983).

Landform on the mainland is mainly characterised by alluvial plains and fans, flood plains and swamplands. The islands region comprises a belt of active volcanoes and associated plains and raised coral islands (Bleeker 1983). Soil fertility ranges from less fertile soils developed on old rocks as part of the Australian continental plate in the southwest of the country to red loams derived from limestone on New Ireland to extremely fertile recent volcanic ash-derived sandy loams on New Britain and in the Popondetta area (Bourke et al. 1981).

Overall, the environment is conducive to all-year-round production of root and tuber crops. However, a number of inherent characteristics could aggravate soil fertility problems, for example, the soils are deficient in two essential elements, potassium (K) and nitrogen (N). Potassium, essential for tuber formation in root and tuber crops, is widely deficient on limestone-derived soils while N deficiency occurs on all soil types, to some degree attributed to the

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farming systems practiced. The minor element magnesium (Mg) is widely deficient on recent volcanic ash-derived soils. In the coral atolls and also in certain areas under grassland and savannah vegetation there is a general lack of topsoil. In high rainfall and steep areas nutrient losses occur through erosion and leaching. Other climatic constraints include the inundation of garden lands in many low-lying areas during the wet season, and the effect of drought in the seasonally dry areas during the dry period. In low population density areas where land is still abundant these constraints are avoided or minimised by farmers selecting good arable sites for gardening.

Root and Tuber Crops

Root and tuber crops are widely distributed throughout the lowlands. Their importance is influenced to some extent by the prevalent agro-ecological conditions. The sweet potato is rapidly becoming the most important staple crop in the lowlands. This is because it is adaptable to a wide range of soil and climatic conditions. Taro has in general declined in importance except in specific places such as the Bainings in East New Britain, Suau in the Milne Bay and other similar areas where cultivation is still practised under the long forest fallow system. Some cultivation of taro also occurs in fertile grassland soils. Yams are always a co-staple with other (staple) crops and are important in areas with marked seasonal rainfall or where rainfall is highly variable. They are a co-staple with sweet potato and taro where rainfall is not so marked, and with bananas in very dry areas. *Xanthosoma* grows in the same broad ecological zone as taro but it is shade-tolerant and produces well under lower soil fertility than taro. Cassava is considered a minor crop but is gaining greater significance in areas with strongly seasonal rainfall where it sometimes attains the status of co-staple. It is important in subsistence gardens in the dry Port Moresby areas and also in certain islands in Milne Bay (Bourke and Kesavan 1982).

Research

The imminent problems associated with the short-fallow system — e.g. declining food crops yields and a build-up of pests and diseases — were realised by researchers as early as the first half of this century. This prompted the establishment of two long-term trials: the three course rotational trial and the soil exhaustion trial at the Lowland Agricultural Experiment Station (LAES) at Keravat in the Islands region. Both trials were aimed at devising alternative cropping systems to the long forest fallow system. Besides these, other soil fertility-related trials included one to assess the suitability of a number of leguminous green manure cover crop and shrub species planted as fallows and, more recently, agroforestry studies. These studies have been documented by Bourke (1977), Leng (1982), Brook (1992) and Brook and Humphrey (1992). As far as individual root and tuber crops are concerned, mainly sweet potato, because of its rapid expansion in the country and its prospects as a saleable commodity and a crop for such institutions as schools, corrective institutions and health centres, has received some notable fertilizer research. The studies were mainly to determine response of sweet potato to various levels of both inorganic and organic fertilizers.

From the literature available, two on-farm fertilizer trials were also carried out on taro because of declining yields and its renown for response to high fertility conditions. The research findings are briefly discussed below.

Sweet potato fertilizer trials — Keravat

These trials consisted of a total of 17 field and six pot trials between 1954 and 1976 on a young volcanic soil at LAES, Keravat, and at various locations in the Gazelle Peninsula (reported by Bourke (1977)). They were conducted to determine the influence of various levels of N, P, K and eight minor elements on two varieties of sweet potato. Seven were conducted in grassland and former forest sites with various cropping histories, the remaining 10 incorporated in the long-term soil exhaustion and rotation trials at the station.

Results showed that nitrogen had the greatest effect on sweet potato yield, especially at grassland sites. However, in the soil exhaustion trial which involved continuously cropping with sweet potato, N depressed yield in three plantings, which was attributed to the use of a variety for which a fertilizer response favoured increased top growth at the expense of tuber production. Phosphate improved top growth and yield in a few trials. In the soil exhaustion trial there were negative responses to residual P in most plantings but large yield responses to applied and residual potash fertilizer.

Potash increased tuber number. There was a response to residual magnesium (Mg) in two plantings and in the pot trials, top growth responses to N, P, K and manganese (Mn).

Fertilizer (N–P–K or N–K) gave large yield increases in the rotation trial. A significant negative relationship was found between the magnitude of fertilizer responses and control yields.

Conclusions from the trials were that in grassland areas nitrogen should be applied at 150 kg N/ha as urea and accompanied by 100 kg K/ha in areas intensively cropped with root crops. In the former forest areas, after a number of years cropping, the application of a moderate level of N (50 kg/ha) was recommended, and where cropping has intensified, both N and K should be applied at 100 kg/ha.

Residual effect of chicken manure on sweet potato at UPNG, Port Moresby

This trial was conducted at the Agriculture faculty garden, Port Moresby, as part of a study to assess yield responses by various food crops to organic wastes. It was conducted to assess the residual effect of chicken manure on sweet potato which followed a fertilised wing bean crop. Rates of chicken manure used in the preceding crop were: 0, 5, 10, 15 and 20 t/ha. Results showed that the optimum level of chicken manure in the trial was 10 t/ha. It produced a maximum yield of 24.86 t/ha of sweet potato which was significantly higher than yields from the other rates, which were not significantly different from each other (Thiagalingam et al. in Bourke and Kesavan 1982).

Effect of applied nutrients on sweet potato at Laloki

This trial was conducted on a silty clay loam soil at the Laloki Agricultural Experiment station near Port Moresby to assess the effect of soil native nutrients and applied nutrients on sweet potato. Fertilizer treatments tested included four levels of nitrogen (0, 20, 40, 60 kg N/ha), two levels of phosphate (0, 40 kg P_2O_5/ha), four levels of potash (0, 20, 40, 60 kg K_2O/ha) and two levels of chicken manure (0, 15 t/ha). N, P and K concentration of the leaf petiole at a specific growth stage was studied to determine in sweet potato yield any relationship between these and any response to the applied nutrients.

Results showed that, except for the effect of N on the percentage of small-size tubers, sweet potato did not respond to any of the applied nutrients in either organic or inorganic forms. Chemical analysis of soil as well as leaf petiole revealed that the soil was fertile and produced a mean yield of 41.6 t/ha. The uptake of nutrients appeared independent of the level of nutrients applied (Velayutham et al. in Bourke and Kesevan 1982).

Fertilizer trials on taro at Lae

These consisted of two researcher-managed trials on a farmer's field at Tikeling village in the Lae district of mainland PNG. This is an area where low and declining soil fertility has been identified as a primary constraint to taro production. The trial objectives were to quantify the response of taro yield and quality to combinations of N, P and K. The rates used included zero to 100 kg N/ha applied in combination with 0, 50 and 100 kg/ha of P and K and conducted over two seasons.

Results showed that treatments that included N at 100 kg/ha had higher yields, i.e. above 13 t/ha. There were clear differences among treatments with other nutrients and between the control and these treatments (DAL 1989).

Farming systems and agroforestry trials at Keravat

The three-course rotational trial

This trial was the long-term rotation trial conducted at LAES Keravat. Food crop yields were used to compare the effects of two rotational treatments, wide and narrow. The wide rotations involved alternating food cropping with a three-year green manure cover crop fallow, the narrow rotation of almost continuous food cropping except for a short-term legume fallow. Results over 19 years (reported by Bourke, cited by Brook (1992)), showed that the sweet potato and taro yields declined markedly over the period. None of the rotations tested offered any promise as an alternative to the traditional long forest fallow system. It was also suggested that in tropical rain forest zones with a high population density and land shortages, recourse to inorganic fertilizers might be necessary.

Alley cropping

The alley cropping trials conducted so far at Keravat have been reported by Brook (1992). The results indicate that, despite the potential of the mulch produced to provide large quantities of nutrients, the use of leguminous hedges failed to improve significantly yields of sweet potato plantings. There were in fact yield decreases recorded in these trials. Some suggested explanations were: (i) yields were impaired by a shading effect in some species; (ii) possible competition from the leguminous hedges for water and nutrients; (iii) the timing of coppicing and subsequent nutrient release from organic matter decomposition did not coincide with the peak period of sweet potato demand; and (iv) the high intensity of rainfall and low Cation Exchange Capacity (CEC) of the soil may have been responsible for rapid leaching of the nutrients after release. Indications were also that alley cropping was labour-intensive, which shed some doubt on its relevance to subsistence farmers.

Adaptive Strategies of Farmers to the Short Fallow System

In villages the conditions forced upon farmers by the intensification of agriculture, subsistence and commercial, have necessitated that they adopt various adaptive strategies to sustain food supplies and to accommodate their increasing cash-crop activities. These adaptive strategies are wide-ranging and include social as well as economic adaptations. Of the agricultural adaptations in the lowlands, perhaps the most notable have been those that have involved modification to the cropping system followed by adoption of some soil fertility improvement techniques, which crudely conform to scientific rationale. However, they still require thorough investigation and confirmation of success before they can be transferred to other areas with similar constraints and agro-ecological conditions. These agricultural adaptations are discussed below.

Change in the cropping system

Modification to the traditional cropping system is probably one of the most significant adaptations that village farmers in stressed areas have undertaken. For root and tuber crops it has involved increased cultivation of the more adaptive and productive crops such as sweet potato, *Xanthosoma* and cassava in place of taro, diploid bananas and yams. The latter are traditional staples in various parts of the lowlands.

In high population density areas as in the Gazelle Peninsula in New Britain, the robust and perennial triploid and tetraploid bananas and *Xanthosoma* have gained prominence as the staples most adaptable to cropping conditions under cocoa and coconut plantings. They are interplanted together with various fruits and nuts species under mature cocoa and coconuts, and provide a continuous source of food supply to households (Ghodake et al. 1995). *Xanthosoma* is also occasionally used as shade for new cocoa plantings. In the grassland areas sweet potato is the main crop. In drier stressed areas as around Port Moresby, bananas and cassava are the main staples. In a number of small islands in Milne Bay they are also the main staples grown to supplement the bulk of food obtained through trade with the mainland and the bigger islands.

From a soil fertility perspective, the adoption of more adaptive and productive crops in the farming system has meant that the expression of nutrition disorders or yield declines has become less apparent or further delayed in the system, especially on the rich volcanic soils.

Composts

Unlike in the highlands, composting is less frequently practised in the lowlands except in the outer atoll islands of Nuguria and Tauu to the north of mainland PNG. The islands are inhabited by a mixture of Polynesians, Melanesians and Micronesians. Their method of composting has been reported by Lefroy (1981). They mainly use composting for the cultivation of swamp taro, the main staple on these islands.

For the islanders, the compost technique overcomes problems of poor soil structure, poor soil fertility, salt spray and lack of fresh water. It involves digging pits down to freshwater level and leaf litter from several species of trees repeatedly added to the pits to produce a rich dark soil at the bottom. Swamp taro is then planted in the pits. During growth leaf litter is regularly added at the base of plants. It takes two to three years for the plants to produce edible tubers.

Rooney (in Bourke and Kesavan 1982) has also reported that taro cultivation by the Nali-speaking people of Manus Province in the past involved no burning and that the branches of felled trees were trimmed and the debris reorganised to ensure continuous ground cover.

Integration of livestock and food plants

In the lowlands a system involving the integration of livestock and food plants is probably at best represented by free-range chickens and feral pigs in villages. The contribution of such a system towards soil fertility improvement is thought to be insignificant because of the open space on which the animals are allowed to forage.

However, in the coral islands such as Paneati in Milne Bay there exists what appears to be a fairly organised system. It involves alternating pigs with food plants. The pigs are confined by fences constructed from coconut trunks. They are fed kitchen scraps or coconut meal till the time they are either sold or slaughtered for a feast. After the pigs have been removed the remaining animal wastes are allowed to decompose fully before the fenced area is planted to food crops. Crop growth observed was fairly vigorous, which seemed to suggest that the decomposed animal wastes were an effective source of plant nutrients.

Legume species in fallows

Results from studies in which the performances of a number of small fast-growing leguminous tree species were tested for suitability as planted fallows have not been promising. They are often difficult to establish due to weed competition, and much labour is required to incorporate the mulch into the soil.

However, indications are that in some places in the lowlands one or two species are able to establish well under the prevalent agro-ecological conditions. The eastern end of Paneati Island in Milne Bay is one such place, where a considerable number of at least one species of a small fast-growing leguminous tree locally known as Kasiu was noticed. It has yet to be identified, but it was probably either *Schleinitzia novo-guineesis* or *Adenanthera pavonina* (Hide et al. 1994). These trees are killed during clearing after a 10–15 year fallow. Those that remain standing give a distinctive appearance to gardens. The leguminous vines (*Pueraria* and *Centrosema*) are also very common in fallows.

Conclusion

In spite of the threat that soil fertility decline poses to the maintenance of food supply in the country, it is only recently that significant research input via agroforestry studies has occurred.

This can be partly blamed on the nature of the problem itself. It often builds up slowly over the years and is not immediately apparent. Indicators such as low yields or food shortages are often marred by certain adaptations, e.g. the use of adaptive and productive crops or imported foods already in place in the farming system. Farmers therefore rarely perceive the problems as critical, and so receive little political and scientific interest.

The country to date lacks the necessary resources and expertise to implement a comprehensive program on nutrition disorders of food crops.

Any successful cropping system that involves agroforestry practices will probably be location-specific and will, to a large extent, be dependent on the existing biological as well as social and economic environments. The use of high-labour input practices such as alley cropping and composting are doubtful, especially among commercially oriented farmers who may not wish to share time or labour between fertility enhancing practices and cash cropping activities.

However, some headway toward addressing soil fertility problems has been achieved through the following:

(i) the participation of DAL research stations in PNG in the ACIAR 9101 project on 'Diagnosis and correction of mineral nutrient disorders in the Pacific';

(ii) the adoption of a farming systems approach to research — while research is being hampered by limited resources at present, it is nevertheless being slowly extended to farmers' fields. Nutrition disorders of root and tuber crops are site-specific and far more likely to be detected on farm than in station plots where remedial measures such as chemicals (fertilizers, fungicides and insecticides) are often applied in order to maintain reasonable yield levels;

(iii) the mapping 'Agricultural Systems of Papua New Guinea' which is being jointly done by the Australian National University, the Department of Agriculture and Livestock and the University of Papua New Guinea, and includes among others such variables as important crops, cultivation intensity, fallow period and type, should reveal many areas within the lowlands that are likely to suffer from soil fertility related problems; and

(iv) there is now an abundance of information available in the literature that could be used to formulate future research strategies.

References

Bleeker, P. 1983. Soils of Papua New Guinea. CSIRO. Australian National University, Canberra, Australia.

Bourke, R.M. 1977. Sweet Potato (*Ipomoea batatas*) fertilizer trials on the Gazelle Peninsula of New Britain: 1954–1976. Papua New Guinea Agricultural Journal, 28. 73–96.

Bourke, R.M. and Bull, P.B. 1983. The lowlands environment. Harvest, 9. 63–67.

Bourke, R.M., Gamble, W.K. and Brookson, C.W. 1981. Executive summary. In: Country Report – Papua New Guinea. South Pacific Agricultural Research Study. Consultants' report to the Asian Development Bank.

Bourke and Kesavan, 1982. Proceedings of the second Papua New Guinea Food Crops Conference. Parts 1 and 2, DPI, Port Moresby.

Brook, R.M. 1992. Sustainable Agriculture Research at LAES Keravat: Report for period June 1990 to March 1992. LAES Technical Bulletin 3/92.

Brook, R.M. and Humphrey, W. 1992. Sustainable Agriculture: A Review of Research in Papua New Guinea up to 1989. LAES Technical Bulletin 4/92.

DAL. 1989. Annual Research Report, Agricultural Research Division, Department of Agriculture and Livestock (DAL), Papua New Guinea.

Ghodake, R.D., Cook, K.E., Kurika, L., Ling, G., Moxon, J.E., and Nevenimo, T. 1995. A rapid rural appraisal of the cocoa and coconut based farming systems in the north east lowlands of the Gazelle Peninsula of East New Britain Province. Technical report 95/1, Department of Agriculture and Livestock, Port Moresby, Papua New Guinea.

Hide, R.L., Bourke, R.M., Allen, B.J., Betitis, T., Fritsch, D., Grau, R., Kurika, L., Lowes, E., Mitchell, D.K., Rangai, S.S., Sakiasi, M., Sem, G. and Suma, B. 1994. Agricultural systems of Papua New Guinea: Milne Bay Province. Working Paper No. 6, Australian National University, Canberra, Australia.

Lefroy, E. 1981. Growing food on coral atolls. Department of Primary Industry, Port Moresby, Harvest, 7. 7–13.

Leng, A. S. 1982. Maintaining fertility by putting compost into sweet potato mounds. Department of Primary Industry, Port Moresby, Harvest, 8. 83–84.

Nutrient Disorders of Root Crops Growing on Raised Coral Reef Landforms Near Madang, Papua New Guinea

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Abstract

Root crops growing in soils on raised coral reef landforms near Madang show interveinal chlorosis of the young mature leaves which extends into new and/or old leaves, depending on the root crop species. Observations and preliminary work indicate that the nutrient disorder observed may be manganese deficiency. The severity of the visual signs of the nutrient disorders varied depending on the root crop species. The yam *Dioscorea esculenta* appears to be the species most severely affected, and taro and sweet potato appear least affected.

RAISED coral reefs make up a significant proportion of landforms in Papua New Guinea (PNG) accounting for 1.5% of its total area (Keig et al. 1987). These areas generally are regarded as fertile (Anon. 1986) and support up to 7% of the PNG population (Keig et al. 1987). There is a considerable area of raised coral reef along the coastal strip west of Madang. The main crops grown along this coastal strip are subsistence root crops and the cash crops cocoa, coconuts and coffee. The yam *Dioscorea esculenta* is the main staple of the people of this region. Cooking banana, taro (*Colocasia esculenta*), tannia (*Xanthosoma sagittifolium*), and the yam *Dioscorea alata* are also important subsistence crops. Sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) are also grown but are of only minor importance.

This paper describes the preliminary examination of a mineral nutrient disorder observed in the root crops growing on the raised coral reef landforms of the Madang region.

Field Observations

Soil

The soils of the raised coral landforms where the nutrient disorders were observed are Rendolls as described by Bleeker and Healy (1980). Rendolls are shallow, dark, weakly acid to neutral soils formed on calcareous parent materials. Although these soils are shallow, they are generally regarded as fertile (Anon. 1986). Bleeker and Healy (1980) found the Rendolls they examined were very well drained with a pH (1:5 H_20) from 6.6–7.9 and of moderate to high chemical fertility. The Rendolls have a high cation exchange capacity (>25 meq%), a high base saturation (>60%), a high nitrogen (N) content (>0.5%), high phosphorus (P) (>20 ppm) and moderate exchangeable potassium (K) (0.2 to 0.6 meq%) and no problems with anion ixation or salinity (Bleeker and Healy 1980).

The pH (1:5 H_2O) of the soil where the nutrient disorders were observed ranged 7.1–7.6 and had a conductivity (1:5) of <0.2 dS/m.

Crop Growth and Symptoms

Yams

The visual signs of the nutrient disorders were most pronounced on the yam *Dioscorea esculenta* and included interveinal chlorosis which was more pronounced towards the leaf margin. Except for the extreme cases, the symptoms first occurred in the young fully expanded leaves. The interveinal areas ranged from pale green to yellow in colour. The transition between the chlorotic interveinal areas and the dark green veinal regions was not distinct and appeared fuzzy. These symptoms persisted in the

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older leaves in which the small veins remained dark green, giving a netted appearance. Other visual symptoms included leaves which were smaller than normal, 'leathery' and very pale with green blotches either side of the main veins. Other leaves were pale yellow–green throughout. Necrotic areas often occurred on the leaf margins and, in severe cases, most of the leaf laminar was necrotic. In plants showing extreme deficiency symptoms, the new leaves and growing tips showed symptoms resembling iron (Fe) deficiency. These leaves were small, very chlorotic or nearly white and often had necrotic margins.

The women of the local village claim that they obtain very little yield from the yams growing where these deficiencies occur.

The yam *Dioscorea alata* did not show symptoms as severe as *D. esculenta.* The only symptom observed in *D. alata* was interveinal chlorosis of mature leaves.

Taro

Taro is grown as an intercrop within the yam gardens. Taro also did not show symptoms as severe as *D. esculenta*. The plants generally had a pale and dull appearance. The mature leaves had pale green to yellow interveinal chlorosis which was more pronounced towards the margins. This is similar to the description of magnesium (Mg) deficiency in taro described by O'Sullivan and co-workers (1995) which may also be characteristic of Mn deficiency which often shows similar visual symptoms to Mg deficiency.

Local women claim that they get adequate taro yield in these areas.

Tannia

The nutrient disorders were observed in tannia as light green to yellow chlorotic interveinal areas contrasting with the dark green veins and surrounding tissue. The interveinal chlorosis was observed in all leaves of the plant but was more pronounced in the younger leaves.

The women of the villages state that tannia yields well in these soils.

Cassava

Cassava is only a minor crop in this region and is generally grown outside the main garden area as a border or along roads, and is used as an emergency food supply. In cassava plants the nutrient disorder was observed as interveinal chlorosis of leaves in the middle region of the plant. The chlorotic areas were more distinct towards the leaf margin. The disorder first appeared as a light green mottling within the darker green veinal regions. The symptoms observed are similar to the Mn deficiency symptoms of cassava reported by Asher and colleagues (1980).

Sweet potato

There is very little sweet potato grown in the area where the nutrient disorders were observed. This may be because it may not be productive in these soils, although the villagers claim that they do not grow it because the village pigs eat it all.

As no sweet potato could be observed growing in these areas, cuttings of the *Ipomoea batatas* cv. Wanmun (a cultivar extensively grown in PNG that has a high level of anthocyanin pigmentation) were planted within a yam garden and observed 38 days after planting. At this time the plants were still relatively small, and the leaves were a pale green colour with little anthocyanin pigmentation. They did not show any of the severe deficiency symptoms described by O'Sullivan and co-workers (1993). The pale green colour, lack of vigour and reduced anthocyanin pigmentation fits the description of N deficiency or the first signs of Mn deficiency (O'Sullivan et al. 1993).

Leaf painting

Leaves of yam, tannia and taro showing nutrient disorder symptoms were painted with a solution of one of the following nutrients: K, copper (Cu), Fe, boron (B), Mg or Mn. Although the results are not conclusive, only Mn appeared to green the leaf tissue. However, the greening was only slight, possibly because observations were made only three days after application.

Future Investigations

Further work is being carried out to identify the nutrient disorders observed. This includes tissue analysis and omission pot trials which will be followed up with field trials to test the validity of the results. It would be interesting to measure the relative reduction in yield of the different root crops due to the nutrient disorder. If the local village women are correct in their assessment of the yield obtained, it may be more beneficial for them to grow taro or tannia than to grow yam.

Conclusion

A nutrient disorder was observed in root crops growing in the Madang region of PNG. Although the disorder has not been positively identified, it is likely that it is a Mn deficiency, for the following reasons: Mn is usually deficient in soils with a high pH; the symptoms observed generally occurred in the young mature leaves and were similar to the visual Mn deficiency symptoms described in the literature; and Mn was the only nutrient to cause leaves to green when applied as a leaf paint to chlorotic leaves.

The severity of the visual signs of the nutrient disorders varied depending on the root crop species. The yam *Dioscorea esculenta* appears to be the species most affected, and taro and sweet potato appear to be the least affected.

References

Anonymous. 1986. Notes from Land Utilisation Section DPI. Harvest, 21(1). 18.

Asher, C.J., Edwards, D.G. and Howeler, R.H. 1980. Nutritional Disorders of Cassava, Department of Agriculture, University of Queensland, St Lucia, Queensland.

Bleeker, P. and Healy, P.A. 1980. Analytical Data of Papua New Guinea Soils. Division of Land Use Research, Technical Paper No. 40. Vol. 2. CSIRO, Melbourne, Australia.

Keig, G., Cuddy, S.M., McAlpine, J.R. and Freyne, D.F. 1987. The Papua New Guinea Resource Information System (PNGRIS). A software package. PNG Department of Agriculture and Livestock, Port Moresby.

O'Sullivan, J.N., Asher, C.J., Blamey, F.P.C. and Edwards, D.G. 1993. Mineral nutrient disorders of root crops in the Pacific; preliminary observations on sweet potato (*Ipomoea batatas*). In: Barrow, N.J. ed., Plant Nutrition — From Genetic Engineering to Field Practice. Kluwer Academic Publishers. 293–297.

O'Sullivan, J.N., Asher, C.J. and Dowling, A.J. 1995. Diagnosis of mineral nutrient disorders in taro. In: Jackson, G. ed., Proceedings of the Second Taro Symposium, Cenderasih University, Irian Jaya and selected papers from the First Taro Symposium. Unitech, Lae (in press).

Mineral Nutrition of Root Crops in Cook Islands

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Abstract

Mineral nutrition of some selected root crops in Cook Islands showed significant response to nitrogen fertilizer. The use of organic fertilizer (azolla) and intercropping legumes indicated some influence on the growth of taro on Mangaia and Atiu Islands. The traditional and sustainable systems of yam in the Cook Islands yield higher than those using chemical fertilizer, but the differences are not statistically significant.

THE Cook Islands comprise 15 islands scattered over a million square kilometres of ocean. There are two distinct types of islands: (i) the Northern Group — all coral atolls; and (ii) the Southern Group — of mainly volcanic origin, with two atolls.

The population of the Cook Islands is approximately 20 000, of whom 9678 live on Rarotonga, the biggest island, latitude 21°–21′S and longitude 150°–46′E. It has a humid tropical climate during the warmer part of the year (October to May) and a subtropical climate during the cooler months (June to September).

Root Crops

The nine root crops grown in the Cook Islands are taro (*Colocasia esculenta*), kumara (*Ipomoea batatas*), tarua (*Xanthosoma sagittifolium*), yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), puraka (*Cyrtosperma chamissonis*), kape (*Alocasia macrorrhiza*), pia (*Tacca* spp.) and teve (*Amorphophallus campanulatus*). Of these, the first five are the most popular in local food production. Puraka and pia are also rated important in the Northern Cook Islands.

Taro, kumara and cassava are the staple food on almost all the islands, and therefore play an important role in the daily lives of the people of the Cook Islands.

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Soil and Growth

Most root crops are grown on the following soil types:

Southern Group — Avana — stony silty clay loam, Matavera — clay loam, Matavera — clay loam, stony phase, Vaikai — clay loam, Vaikai — clay loam, buried soil phase, Tikioki — clay loam, Arorangi — clay loam, Tamarua — clay loam (Mangaia, Mauke and Atiu islands), Rangimotia (Mangaia island), Nuata (Mauke island), Te Autua (Atiu island), Mangarei (Mitiaro island), and Tautu, Nikaupara, Tongarutu, Rakautai and Vaipeka (Aitutaki island).

Root crops grown on these soil types show few mineral nutrition problems except occasional nitrogen or potassium deficiencies, especially with the dryland taro varieties such as Niue Matie. Only rarely are deficiencies of this sort found in puraka. Overall, root crops in the Cook Islands perform reasonably well on these soils.

Northern Group — The only soil type on the atolls in the Cook Islands is known as Muri sand. This is young soil formed from comminuted reef coral on the constructional beach ridge that fringes the island between the flood plains and lagoon. It has no subsoil and the parent material (white coral sand) is within 25 cm of the soil surface. The parent material is loose, structureless and coarse sand-textured. There being no other soil type, the residents of these islands have no option but to try to grow crops in this soil type.

Root crops such as tacca thrive well on this sandy soil. Puraka and taro are two other root crops that produce amazingly well in this soil in low-lying areas close to the water table.

Taro growing on Muri sand often shows yellowing of the leaf blade. Sometimes plant growth is reduced and often the plants die prematurely. Other root crops such as kumara, cassava and tarua also show yellowing symptoms.

Mulching and composting are common practices for this soil to minimise mineral deficiencies and to ensure food crops yield well.

Crop Response

A number of experiments comparing yields from different fertilizer rates and agronomic treatments have been conducted in the Cook Islands. The results of these experiments are summarised below.

Nitrogen fertilisation, lowland taro

Nitrogen fertilisation resulted in tall plants with big leaves, though its effect on the number of shoots per plant was not apparent in the study. Niue Po and Niue Matie were responsive to fertilisation in terms of all growth characters except shoot number per plant. With Niue Po, highest corm yield was obtained with 100 kg N/ha. With Niue Matie, the highest yield was obtained with 200 kg N/ha (Table 1). Veo did not respond to N applications.

Table 1. Effects of different levels of nitrogen on corm yield (t/ha) of different varieties of taro grown under lowland conditions.

	Nitrogen rate (kg/ha)					
Variety	0	50	100	150	200	250
Niue Po	8.7	10.7	15.3	11.7	12.4	10.6
Niue Ma	7.1	9.5	10.2	8.7	10.3	10.2
Veo	6.4	5.5	6.0	5.2	6.5	6.3

Green azolla fertilisation, upland taro

The incorporation of azolla, irrespective of method, resulted in tall plants with large leaves and plenty of shoots but lower dry matter content. Niue Matie was the most responsive variety to azolla fertilisation when determined on the basis of plant height, leaf area and dry matter content. Veo produced the most shoots or suckers.

Intercropping taro with legumes

The effects of four intercrops, mungbean, blackgram, horsegram and cowpea, on raised bed swamp taro, were measured. The taro–mungbean combination gave the highest gross return without significant reduction in taro yield. Mungbean and cowpea were quick and vigorous in growth. Reduction in taro yield was dependent upon the period of time in which there was competition between the taro and intercrop (Table 2).

Table 2. Yield of taro with and without legume intercrops (values followed by the same letter are not significantly different (P=0.05)).

Treatments	Yield t/ha	
	Taro	Intercrop
Taro (mulched)	25.4 a	—
Taro + mungbean	23.8 a	1.23
Taro + blackgram	19.8 b	0.61
Taro + horsegram	17.6 bc	0.56
Taro + cowpea	15.9 c	1.34
Taro (non-mulched)	16.5 bc	—

Yam, organically grown and with artificial fertilizer

The treatments were as follows:—

1. Dug pits plus 600–700 kg fresh organic matter (banana stumps, leaves, etc);
2. NPK (11:2:15) at 300 g/6m^2;
3. NPK plus organic matter in a dug pit as in treatment 1; and
4. Control.

Two yam varieties, locally known as Toka and Etene, were grown. The experimental design was a 2×4×3 split plot, i.e. (2 varieties, 4 treatments and 3 replications) at the following dimensions: subplots, 6 m × 1 m; plots, 12 m × 1 m; and blocks, 12 m × 8.5 m.

Results of the experiment are summarised in Table 3 and show the Toka yams in the NPK plus organic matter treatment and the organic matter alone treatment gave significantly higher yields than the control. There was no significant difference between the control and the NPK treatments.

The Etene yams tended to yield higher than Toka in most treatments but there were no significant effects between the treatments. As with Toka, the NPK plus organic matter treatment gave the highest yield.

Table 3. Yields of yams kg/plot supplied with combinations of organic matter and chemical fertilizer (values in the same column followed by the same letter are not significantly different at P=0.05).

Treatments	Toka	Etene
Organic matter	91.5 a	91.5 a
NPK	72.2 ab	79.2 a
NPK plus o/matter	93.0 a	108.3 a
Control	51.7 b	94.0 a

LSD = 34.8 kg within the same variety.

Research Needs

Research into the following aspects of root crop production is needed:

- Root crop mineral nutrients application systems for atolls;
- The application of organic fertilizer to root crops via bi-wall drip irrigation systems;
- Fertilizer requirements for certain root crops grown on the hill slopes of Rarotonga;
- The effects of azolla on the yield of paddy taro; and
- A root crop network for the region is needed.

Bibliography

Bhatt and Makakea 1992. Root Crop Research Report, Atiu Island. Ministry of Agriculture, Cook Islands.

Juanito, L., San Pedro, Vivia Tangatataia, Ngarangi Tuakana, Teinakore George, Itimanga Tereapii, Taokia and Teremanuia Tangianau 1992. Root Crop Research Report, Mangaia Island. Ministry of Agriculture, Cook Islands.

Purea, M. 1982. Evaluation of the performance of 36 Nuiean taro varieties under Rarotonga conditions. Research Bulletin, Research Division, Ministry of Agriculture, Cook Islands.

Totokoitu Research Station Annual Report 1992 and 1993. Ministry of Agriculture, Cook Islands.

The Agronomy of *Cyrtosperma chamissonis*, *Colocasia esculenta* and *Ipomoea batatas* in Kiribati

I. Ubaitoi[1]

Abstract

Root crops are the major staple foods on the 33 atolls that constitute Kiribati. Babai or giant swamp taro *(Cyrtosperma chamissonis)*, taro *(Colocasia esculenta)* and sweet potato *(Ipomoea batatas)* are the principle edible root crops grown.

Babai is the most important crop and it is grown using traditional methods of cultivation, handed down in secret from generation to generation. This crop is culturally significant and can produce corms up to 100 kg in weight. Island people cultivate the crop in pits dug to water table depth and amended with compost made from local plants. Production is very labour intensive.

Where possible taro and sweet potato are cultivated in trenches dug in deep soils with high organic content. Most of the coral soils are deficient in nitrogen, potassium and trace elements such as iron, manganese, zinc and copper. As for the giant swamp taro, compost is the main amendment used. Rusty crushed tins may be added to combat iron deficiency. Small additions of a complete fertilizer give good crop responses, but care must be taken to avoid over-fertilising that pollutes the fresh water lens in the atoll.

KIRIBATI islands are low-lying atolls, scattered astride the equator, over 3 million km^2 in the Central Pacific, 33 islands divided into three main groups: the Gilbert group (17 islands), Phoenix group (8 islands) and the Line group (8 islands). Tarawa, in the Gilbert group, is the capital of Kiribati. According to the 1990 census, the total population was 72 335.

Root crops are considered the major food groups in atolls. The principal edible root crops commonly grown in Kiribati are babai or giant swamp taro (*Cyrtosperma chamissonis*), taro (*Colocasia esculenta*) and sweet potato (*Ipomoea batatas*). Their agronomy is discussed.

Culturally babai is by far the most important root crop in Kiribati. The traditional methods of babai cultivation have been developed over many generations and are generally kept within the family, revealed only to immediate members of the family. The size of the babai corm grown indicates worth as a farmer and social standing.

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Taro (*Colocasia esculenta*) is less important in Kiribati but of considerable importance in Tuvalu, Cook Islands, Tokelau and parts of Micronesia. However, a small amount is grown on most islands.

Sweet potato (*Ipomoea batatas*) is occasionally grown on a small scale in home-gardens in Kiribati. Yields are often disappointingly low. Sweet potatoes are considered to have advantages over the edible aroids, giving high yield within a short time. Most cultivars reach maturity in three to five months.

Varieties

Cyrtosperma chamissonis

Since no systematic work is being carried out on the agronomy of *Cyrtosperma chamissonis*, there is no certainty about the actual number of different cultivars of this crop, but Ali (1987) collected 24 cultivars and reported their characteristics. The varieties described vary considerably in eating quality, time to maturity, and morphology.

Colocasia esculenta and Ipomoea batatas

Taro and sweet potato cultivars have been distributed to Kiribati by the former Fellow Agriculture, USP Atoll Research and Development Unit and the Pacific Regional Agricultural Programme (PRAP). According to PRAP the following (Table 1) are the recommended varieties for taro and sweet potato in Kiribati.

Table 1. Recommended varieties and spacing of taro and sweet potato for Kiribati.

Crop	Spacing	Varieties
Taro	10.3	Samoa hybrid, Tausala ni mumu, Alafua sunrise, Intelpelyar, Samoa
Sweet potato	10.5	L329, TIB 2, Funafuti white

Botany

Cyrtosperma chamissonis

Cyrtosperma chamissonis is the largest plant that produces an edible corm. The height of some cultivars, e.g. 'te ikaraoi' may reach three to four metres. It lives a long time, some cultivars up to 15 years, but 10 years is quite common.

Corm size is variable, weighing from 2–100 kg, although 50 kg is more common. The corm is the stem of the plant and suckers arise from it. The leaves grow directly from this, the roots growing from its sides and lower end. The shape of the corm may vary from conical to an almost perfect sphere. Some cultivar corms are branching, e.g. Natutebubua.

Fibrous roots emerge from the corm side as well as from the base. The true roots have air spaces in the cortex which enable them to exchange gases in the swamp. These roots are usually found in the compost basket, have a poorly developed root cap and are known to have no hairs.

Cultivation

Much effort is required in the cultivation of babai (*Cyrtosperma*). Babai is usually grown in pits where water is always available, and is the only plant cultivated carefully in Kiribati. The only source of water for the crops is the fresh water found floating at a variable depth on the salt water. The freshwater lens varies in depth below ground surface, depending on the island's height at sea level. The size of the water lens is in proportion to the width of the raised part of the atolls. In narrow islands, there are few babai pits because the islands have no good water reserves; the wider islands have many babai pits because of wider and thicker water lens and therefore greater water reserves of better quality (Webb 1994).

Pits are dug to the water table with an average width of seven metres, the length of any size, 5–20 metres or more. Planting procedures vary, and most islanders have secret methods not known to others except their own families. However, one typical planting method includes making the pit the required size. Further digging is carried out to make a hole in accordance with the size of the planting material, approximately 30–50 cm in diameter. The hole is then backfilled with prepared dry and chopped green leaves, topped with a thin layer of black soil rich in organic matter. The placement of black soil at the top is important because it assists in the prevention of burning the young plant from heat generated during fermentation of the leaves. A young seedling or a set (top of the plant from which the corm has been cut) is planted in the middle of the hole (Ali 1987).

Cyrtosperma growers devise their own special materials for compost mixtures. They collect the readily available compost material on their islands, e.g. *Artocarpus altilis* (te mai), *Guetarda speciosa* (te uri), *Tournefortia argentea* (te ren), *Scaevola taccada* (te mao), *Hibiscus tiliaceus* (te kiaiai), *Sida fallax* (te kaura), *Cordia subcordata* (te kanawa), *Pisonia grandis* (te buka), *Pandanus tectorius* (te kaina), *Triumfetta procumbens* (te kiaou), *Vigna marina* (te kitoko), *Morinda citrifolia* (te non), *Cassytha filiformis* (ten tanini) or *Cocos nucifera* (te ni).

Some cultivars are early maturing like 'katutu'. This cultivar does not require a lot of labour but requires minor work like topping up the base of the plant with mud, whereas late-maturing cultivars such as 'ikaraoi' involve a lot of labour. The work involves making a basket out of pandanus or coconut leaves and backfilling it with prepared compost either dry or in its fresh stage. According to *Cyrtosperma* growers, the plant is composted quarterly. For a grower to know the time of composting application, he or she has to observe closely the emergence of new leaves that come out approximately every month; after the third leaf comes out, it is time for the planter to apply compost.

Colocasia esculenta and Ipomoea batatas

Taro and sweet potato cultivation in Kiribati also involves much input for a successful crop. Recommended cultivars are tolerant to local soils and conditions. However, they will not thrive on any site. It is therefore important when selecting digging grounds for taro and sweet potato to avoid areas with a shallow soil on top of a hard pan, rocky ground or gravelly soils, areas where ground water is known to become brackish during drought or areas which flood for extended periods during the rainy season (Webb 1994). Other factors to consider are exposure to salt-laden winds, availability of space and sunlight, and competition from other plants. The ideal location is preferably close to the household water-drawing area on the protected lagoon side, with good quality water. A site with a good topsoil layer, because of its high organic matter content, also helps ensure good results (Webb 1994).

The methods of production briefly described below are applicable to the cultivation of taro and sweet potato.

Tree crops research method of production

The trenches are dug 30 cm wide and 30 cm deep, at 1 metre spacing, length depending on the size of the garden. Because of the highly permeable nature of the soil and the variable rains, sunken beds are advisable in order to concentrate and retain as much water as possible.

The constituents of the compost may vary with location and availability of material. A list of potential backfilling materials is modified from Webb 1994:

green leaves of any common species (te uri, te mao, te ren),
dead leaves (te uri, te buka, breadfruit),
rinsed seaweed,
manure and/or topsoil from chicken or pig pens,
any rusting metal, e.g. crushed tins (rusty steel has been used in cultivation in Kiribati for many years to combat iron deficiency in plants),
other materials, e.g. fish and animal waste, such as ground and pond algae, sea cucumber, rotten breadfruit, telapia, any organic waste,
rotten coconut logs, husks and coconut root peat,
crushed pumice or soil from a guano outcrop,
black soil.

The trench is then backfilled with as wide a range of materials as possible. The bottom layer is usually made up of coconut husks mixed with rusty tins, as these take a long time to decompose and could pose a problem to root development if too close to the surface. Ingredients are placed in thin layers with a layer of black soil and manure between each, then the trench overfilled so that it is raised above ground level by about 30 cm. Sufficient water is added to moisten each layer to hasten decomposition of the compost. The final layer should be heavily mulched soil to avoid drying out. Because of the large amount of unrotted material used in backfilling, the trench takes considerable time to be ready for planting. A period of 6–7 weeks is considered the minimum but it depends on how often the hole is aerated and watered, and the quality of the materials used (Webb 1994). Generally the trench is ready when it has sunk to the level of or just below the surrounding soil due to the decomposition processes.

PRAP

The trench size is as described above. The backfilling technique is different, i.e. the compost mix is decomposed before applying to the trench. The compost mix has the following components:

25% dead leaves of te uri, te mao, te ren and other species especially leguminous and nitrogen-fixing trees such as *Sophora tormentosa* or *Vigna marine,*
25% well-rotted coconut log broken into small pieces,
25% soil or sand, and
25% manure (chicken and/or pig).

These ingredients (a rough measure could be a bucket or a bag of each type) need to be mixed thoroughly. If well-rotted leaves and the matured manure (old, not fresh, to prevent burning of plants) are applied, then the compost can be used immediately.

Either one of these two methods can be used in accordance with the availability and stage of decomposition of the compost ingredients.

Plant Nutrient Requirements

Cyrtosperma

Very little is known about plant nutrition requirements. The only plant nutrients applied are in the form of organic matter — plant leaves. According to Ali (1987), no accurate data on the quantity of composting material applied to a single plant are available. It is estimated that 60-70 kg of dry or green leaves may be required to grow a single plant over 4–5 years.

Sweet potato and taro

Kiribati coral soils are shallow, well-drained and deficient in nitrogen, potassium and trace elements, especially iron, manganese, zinc and copper. In addition, because of the naturally high pH, even if nutrients are added as fertilizers they may not benefit the crops planted, as many important nutrients are not available to plants in such alkaline conditions. The preparation of a planting hole or trench with compost, and later the addition of organic matter, can make the pH of the soil more neutral, thus increasing the ability of plants to utilise any nutrients present in the soil (Webb 1994).

Table 2. Fertilizers recommended for use in Kiribati (Trewren 1986).

Kiribati general mix			
Fertilizer	Quantity (kg)	Element in mixture	(%)
I.B.D.U.	31.0	N	(9.9)
Triple superphosphate	27.0	P	(5.1)
Potassium chloride	30.0	K	(12.0)
Iron sulphate	9.0	Fe	(1.8)
Manganese sulphate	1.8	Mn	(0.41)
Zinc sulphate	0.8	Zn	(0.184)
Copper sulphate	0.4	Cu	(0.10)
Total	100.0		

Addition of small amounts of complete fertilizer mix (Table 2) to the compost is helpful and sometimes necessary to bring about the successful growth and maturity of the plant (Trewren 1986). Low rates of fertilizer are used to make applications affordable by the majority of growers and also to pose lower risks of pollution of the water lens. The fertilizer rate used in planting trenches has been a single dose of 100g of General Mix incorporated in a 3-metre trench, but satisfactory results have also been obtained without inorganic fertilizer addition.

References

Ali, A. 1987. The agronomy of *Cyrtosperma chamissonis* Schott in Kiribati. Alafua Agri. Bull.

Trewren, K. 1986. Charcoal: a useful additive to fertilizer for coral soils — an experiment in Tuvalu. Harvest (Papua New Guinea) 12: 16–18.

Webb, A.P. 1994. Tree and Perennial Crop Introduction and Extension in Kiribati 1991-1994. Ministry of Environment and Natural Resources Development, Kiribati.

The Incidence of Taro Leaf Blight (*Phytophthora colocasia*) in Relation to Rainfall in Western Samoa: a Progress Report

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Abstract

An investigation is being conducted on taro leaf blight (*Phytophthora colocasia*) in relation to rainfall in Western Samoa. The preliminary results showed a positive relationship for taro leaf blight disease to rainfall and plant age. A negative relationship appeared to exist between the disease damage and the eating quality of the corm. A possibility of growing taro as a seasonal crop is suggested in order to minimise cost of production.

IN Western Samoa, taro (*Colocasia esculenta*) was the main staple food and also a major export crop. Success in efforts to realise this potential depends largely on the capacity to overcome the many constraints while intensively exploiting the various systems of taro cultivation. The effects of natural hazards can be a major constraint, as demonstrated by the highly destructive taro leaf blight (TLB) disease, which has been infecting taro in Western Samoa since July 1993. A recent report released by the Central Bank of Western Samoa showed a marked decrease in taro export in 1994. It dropped from an annual average of about 184 000 cases during 1988–1993, to about 2000 cases in the first nine months of 1994 (Anon. 1993, 1994).

A major task for the Ministry of Agriculture, Forests, Fisheries, and Meteorology (MAFF&M) in the immediate term is to revitalise the taro industry. Work has centred on the use of chemicals and sanitation technologies, in an integrated control package to combat the disease. This approach has been quite successful, but such a recommendation must have some degree of flexibility in order for the resource-poor farmers to maintain production at a sustainable level.

For certain diseases, such as downy mildew of hops, a 'weather index' can be used to determine the time and number of spray applications for its control (Solarska 1991). Similarly, this approach might be applicable in establishing a 'flexibility index' for the control of TLB in Western Samoa. This is particularly important because of the differences in rainfall at the various sites on Upolu and Savaii Islands. According to Wright (1963), the southern side of Upolu is relatively rainy, with an annual average rainfall of 4063 mm. The northern rainshadow area has an annual average of about 2813 mm. This difference in rainfall has been observed to be related to the incidence of TLB, and affects the frequency of chemical applications (personnal communication with farmers). The implications for production cost are assumed to be quite significant, considering an unsubsidised price of about WST50.00 (approx. $A26.50) for one litre of Foschek, which is currently used for the chemical control of TLB.

The objective of this paper is to present some preliminary findings on the interrelationships among rainfall, incidence of TLB, frequency of spray applications, growth, yield, and eating quality of the corm.

Materials and Methods

The experiment is being conducted on Upolu Island in Western Samoa (latitude 13°–51′ and longitude 171°–47′W) by the Research Division of MAFF&M. The planting treatments were administered in August, October, December of 1994, and February, April and June of 1995 (time of planting), in four replicates (sites): Siumu, Nuu, Saleimoa and Faleolo.

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The trial layout is a randomised complete block design.

The plots measuring 43 m × 11 m gross (528 plants) and 19 m × 9 m × 2 net (400 plants) have been planted with taro headsets (cultivar Niue) at 1 × 1 m spacing, and harvested at seven months maturity.

Thirty-two plants per plot have been used for the assessment of growth and TLB. Every leaf is numbered at emergence, and the accumulative total during the period from planting to harvesting is a measure for growth. For TLB assessment, each leaf is monitored regularly for number of lesions and disease severity. The assessment of the latter is based on a diagramatic scale (1 = no infection; 6 = severe infection) of Gollifer and Brown (1974).

A systemic fungicide, Foschek, has been used to control the disease, at 200 mL per 10 litres of water. Spraying has been done using a mistblower when the disease severity reaches a score of about 2.5 at the different sites.

Fresh corm weight was measured for each plot at seven months maturity.

Rain gauges were installed at Siumu and Saleimoa for the daily recording of rainfall by the farmers. Information for Nuu and Faleolo is being made available at the Station and the Meteorological Centre, respectively.

Results

The parameters (disease severity, growth, yield, and eating quality of the corm) were similar between the rainy (Siumu) and rainshadow (Saleimoa) blocks, except for the amount of rainfall and number of spray applications (Table 1). During this investigation, the average monthly rainfall at the wet area (Siumu) was roughly twice the amount of that at the dry area (Saleimoa). At the same time, the number of spray applications in the wet area had at least doubled the amount applied to the dry area.

The TLB infection was minimal during the first two months after planting. An increasing trend was observed parallel to plant age, and it appeared to be most prominent beginning at about four months of maturity. This pattern coincided with enhanced leaf senescence. Out of 21 leaves observed between planting and harvesting for a seven-month-old taro, about four functional leaves had been maintained by the plant at any one time of the investigation.

The corms from the two distinct rainfall sites were relatively small, compared to a good marketable-sized corm normally at the market before TLB. Close to 3000 kg/ha was the average yield, and generally of good eating quality.

Table 1. Characteristics observed on taro grown on rainy (Siumu) and rainshadow (Saleimoa) areas during the wet season months.

Observations	Wet area	Dry area
Rainfall monthly average (mm)	531	281
Disease severity		
- 12 days maturity	1.0	1.1
- 75 days maturity	1.7	1.5
- 130 days maturity	1.8	2.4
- 201 days maturity	2.0	2.4
Number of spray applications at about 2.5 disease severity (from planting to harvesting)	12	5
Growth (leaves per plant) average from planting to harvesting	22	20
Yield (kg/ha) at 9880 plants/ha, 0.3 kg average corm weight and 7 months maturity	2964	2964
Eating quality of the corm Score (4 = top quality; 1 = poor) (boiled then tasted)	3.6	2.9

Discussion

The results confirm the positive relationship between the amount of rainfall and the level of TLB infestation. This was reflected in a more frequent number of spray applications at the wet area. This kind of relationship is quite common with fungal diseases (Gambrah-Sampaney, 1990; personal experience with banana leaf spot). An increase in the frequency of spray application in a wet area was useful in maintaining the severity of the disease between the two rainfall zones at equivalent levels. The same concept of disease control would be applicable in relation to plant age, due to a high risk associated with increasing levels of inoculum.

By maintaining the severity of the disease between Siumu and Saleimoa at equivalent levels, their actual yields were similar in both quantity and eating quality. However, the latter appeared to be more sensitive, with greater negative reponses in relation to TLB. As indicated in the eating quality of the corm, the slightly lower quality of the Saleimoa taro could be attributed to a corresponding higher incidence of the disease.

It should also be noted that this part of the experiment was implemented during the wet season months, when the amount of rainfall for the dry area is expected of the wet area during the dry season months (Wright 1963). Therefore taro could be grown on the wet side of the island during the dry season months, with a significant reduction in spray applications. This warrants further studies on taro growing as a wet season crop in the north and as a dry season crop in the southern part of the island. This might minimise the use of chemicals without sacrificing yield.

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References

Anonymous, 1993. Central Bank of Samoa Bulletin, June 1993.

Anonymous, 1994. Central Bank of Samoa Bulletin, December 1994.

Gambrah-Sampaney, G. 1990. Aggregate Supply Response of the Cocoa Industry of Trinidad and Tobago; 1952–1986. University of the West Indies (Trinidad).

Gollifer D. E. and Brown J. F. 1974. Phytophthora leaf blight of *Colocasia esculenta* in the British Solomon Islands. Papua New Guinea Agricultural Journal 25(1:2), 6–11.

Solarska E. 1991. Forecasting and signalling of downy mildew of hop — results of practical application in 1986–1988.

Wright A. C. S. 1963. Soils and Land Use of Western Samoa. New Zealand Department of Scientific and Industrial Research.

Use of Leguminous Trees to put N into Pacific Farming Systems: Solution in Search of a Problem?

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Abstract

Leguminous trees have the potential to provide large amounts of nitrogen-rich biomass to Pacific Island farming systems. This paper reviews the use of leguminous tree species in root crop production systems, outlines some of the factors which may affect nitrogen fixation capacity, and comments on the choice of appropriate tree species and management from a farming systems perspective. It is concluded that in root crop systems N-fixation will not be the primary characteristic used by farmers in tree selection.

THE use of leguminous trees to provide nitrogen and other benefits to farming systems has been popularised and promulgated since the major work on alley cropping at the International Institute for Tropical Agriculture (IITA) in the early 1980s (Kang et al. 1981). Leguminous plants can produce large amounts of biomass, which can release nutrients to increase soil fertility, reduce fertilizer needs (Yamoah et al. 1986), and increase crop yields (Hussain et al. 1988).

Early alley cropping experiments were concerned mainly with nitrophilic crops such as maize that respond readily to nitrogen (N) inputs provided by prunings from leguminous hedgerows (Kang et al. 1981). However, the principal staple foods in most Pacific Island countries are root crops, and reports of positive benefits from tree legumes in root crop production systems are more difficult to find. Indeed, high N levels in newly cleared forest soils or applications of N fertilizer can result in vigorous top growth with low tuberisation in crops such as sweet potato and cassava (Van Wijmeersch, pers. comm.).

The capacity to fix N might be expected to convey a distinct advantage in the choice of a hedgerow species. However, interactions between hedgerow species, the crop and the soil are complex, there being numerous factors besides N-fixation that impinge upon the interactions in these systems (Garrity and Mercado 1994). This paper reviews information on the use of leguminous tree species in root crop production systems in Pacific Islands, outlines some of the factors which may affect N-fixation capacity, and comments on choice of appropriate tree species and management from a farming systems perspective.

Empirical Evidence

Direct attempts to relate soil N supplied from tree prunings to root crop production in the Pacific Islands are limited. Brook (1993), reporting on an alley cropping trial conducted at the Lowlands Agricultural Experiment Station in Papua New Guinea, concluded that all hedgerow species tested provided N in quantities greater than the intercropped sweet potato requirements, which resulted in greater vine growth at the expense of tuber formation. This worker also considered shade from the hedgerows detrimental to crop yield and concluded that the prospects of this land-use system for sustaining sweet potato yields were not promising. In Solomon Islands studies have indicated that the yields of both sweet potato and cassava are low in alley-cropped plots (Hancock 1989).

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In contrast, Weeraratna and Asghar (1992) demonstrated increased available nitrogen (NH_3-N and NO_3-N) during weeks 2–6 after the application of 30 and 60 t/ha of Dadap (*Erythrina* spp.) mulch to taro (*Colocasia esculenta* L. Schott) plots, with a subsequent significant increase in dry matter yield of corms compared to non-mulched control plots. Rogers (1995) reported positive effects of alley cropping on taro yield only after five years of continuous cropping and mulch application with prunings from *Calliandra calothyrsus* or *Gliricidia sepium* on a Typic Humitropept in Western Samoa. In the first four years of this trial there was no significant difference in crop yield between the alley plots and the no-tree control plots (Rosecrance et al. 1992).

Yield data from an on-farm trial established at Poutasi in Western Samoa in September 1990, to evaluate *Erythrina subumbrans* interplanted at 2 × 2 m spacing with taro and to compare this system with a *Glyricidia sepium* alley treatment with trees planted in hedgerows spaced at 5 m and a no-tree control, are shown in Figure 1. The data indicate advantages in the tree plots from year two onward, with the *Erythrina* plots being the most productive. In year four the plots were planted with a mixture of *Colocasia* and *Xanthosoma* taro because of the outbreak of taro leaf blight in Samoa. The overall lower yields in this year are due to blight infection of the *Colocasia*. Positive effects of both tree species on crop production and sustainability of yield are evident in this trial.

No published data on the effects of leguminous tree mulch in yam production systems in the Pacific Islands could be found in the literature. Yams are high demanders of soil N (Young 1976) and are frequently the first crop grown in freshly cleared forest soil. In Western Samoa farmers use mature *Erythrina subumbrans* trees as live support for yams; about 5–6 setts (*Dioscorea nummularia*) are planted in a circle 2–3 m from the base of the tree and allowed to climb up bamboo stick buttresses to the bole of the tree. The growing yam vines eventually cover the canopy and suppress the tree growth over the growing period. Green leaf prunings from the *Erythrina* are used as mulch at the time of planting the yams. Further work to validate the benefits of this system and

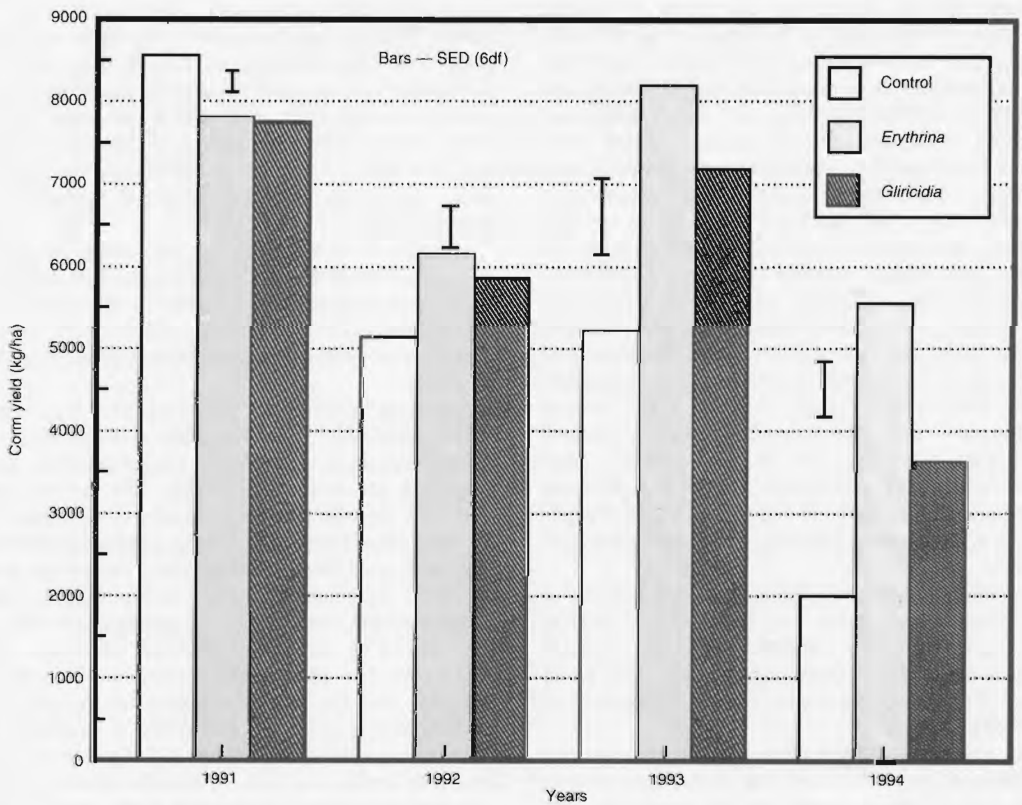


Fig. 1. Taro yields at Poutasi over four consecutive years.

to tune the management is being carried out by the Pacific Regional Agricultural Programme (PRAP) farming systems project in Western Samoa.

Nitrogen Fixation

Many small farmers in developing countries cannot afford to buy chemical fertilizers, or the supply is erratic and fertilizers are not available when needed. From both the ecological and economic standpoints the advantages of in situ N-fixation by the components of the agricultural system are attractive (Garrity and Mercado 1994). Addition of N to the system, however, is not guaranteed simply by planting a leguminous tree species. Not all these species have the ability to nodulate and fix atmospheric N.

Several workers in the Pacific Islands have reported levels of biomass production from coppiced leguminous tree species and leaf N content (Brook 1992, 1993; Tekle-Halmanot et al. 1991; Rogers 1995). Estimates of possible N additions from the leaf prunings have ranged from 29 to over 300 kg/ha per year, but no records could be found of direct measurements of N-fixation of levels of active nodulation of the trees in the trials. It is difficult, therefore, to know how much of this is N-accretion in the system and how much is recycling. Ladha and co-workers (1993) working in the Philippines, estimated N-fixation in *Gliricidia sepium* may account for 30–60% of plant N uptake, but because a leguminous tree is reported to fix N somewhere does not mean that it will always be able to do so. The presence of suitable rhizobia is essential to N fixation. In fields that have not been successfully planted to a given N-fixing tree (NFT), it is likely that the introduction (inoculation) of suitable bacteria will be beneficial (MacDicken 1994). Furthermore, any factor in the environment that affects the growth of the host plant is likely also to affect nodule development and function (Dixon and Wheeler 1983). Low pH (below 5.5), low soil P levels, water stress, reduced oxygen levels, salinity and shortage of micronutrients such as cobalt, iron and molybdenum, are all factors that may reduce or inhibit N-fixation.

Garrity and Mercado (1994) pointed out that a high demand for P to service the N-fixation process may result in severe competition for this nutrient between NFTs and annual crops. This may be of special significance on some of the P-fixing soils in the Pacific Islands.

Few studies have been carried out to evaluate tree management on nodulation and N-fixation. Nygren and Ramirez (1993) reported on the phenology of N-fixing nodules in pruned clones of *Erythrina poeppigiana* in Costa Rica. Dramatic changes in nodule biomass were observed during a six-month pruning cycle. Nine weeks after pruning nodule biomass was almost nil but had increased to above the pre-pruning level by 17 weeks after pruning. They linked the nodule phenology of pruned *Erythrina poeppigiana* to availability of photosynthate. Clearly, further studies to investigate the effects of rigorous pruning in hedgerow systems on nodulation and N-fixation are required.

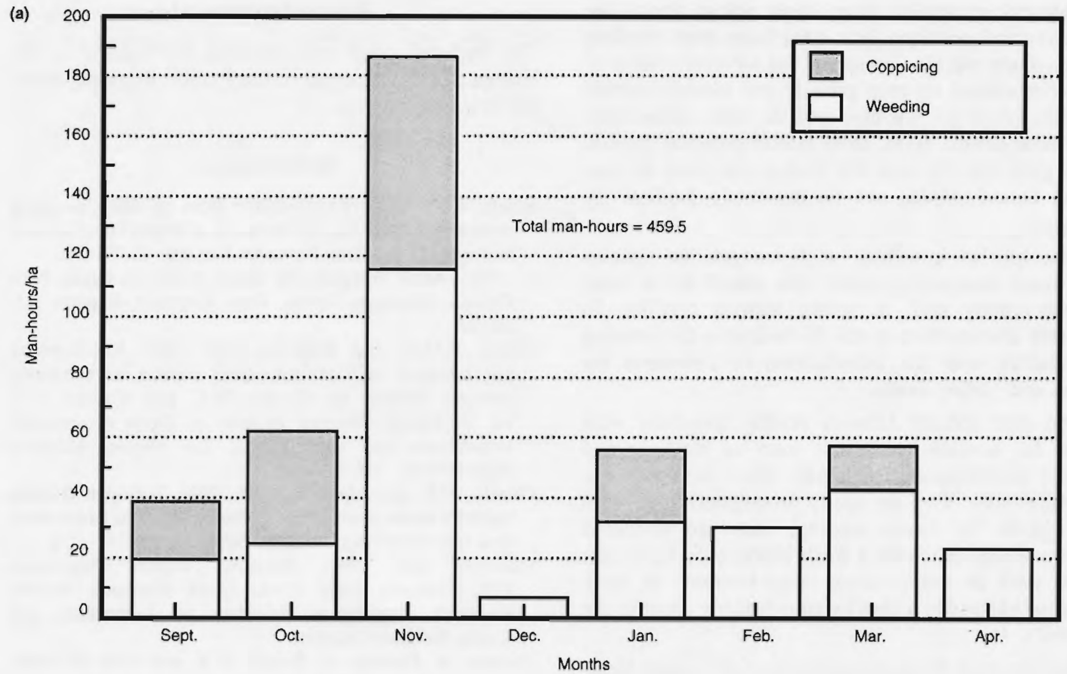
The rate of release and supply of nutrients from decomposing prunings also needs to be carefully considered. Synchronising the release of nutrients with crop demands is important, particularly in high rainfall areas where leaching can rapidly remove nutrients from the root zone. When prunings are applied to the soil surface as mulch, N may also be lost by volatilisation. Knowlege of the rates of litter decomposition offers opportunities to manipulate the timing of nutrient release and improve the efficiency of the system (Young 1989).

Farming Systems

Leguminous trees have been used extensively in Pacific Islands farming systems as shade for cocoa and coffee. *Gliricidia sepium*, *Albizia chinensis* (syn. *A. stipulata*), *Leucaena leucocephala* and *Erythrina subumbrans* are commonly used in this way. The primary function of these trees is to provide shade to the tree crop, but they undoubtedly add organic matter and some N to the system through leaf fall and loppings.

Farmers in Western Samoa also recognise *Erythrina subumbrans* as a valuable tree in root crop systems. As mentioned above, they use this tree as live support for yams, but also to enrich fallow periods and, intercropped, to improve taro yields (Rogers et al. 1993).

However, attempts to introduce new leguminous tree species into food cropping systems have frequently resulted in increased labour demand and a change in the labour use profile. The systems have therefore proved unpopular and/or unadoptable by resource-poor farmers. Trials in Samoa demonstrate that, with appropriate management, labour use in the tree plots can be similar to or less than that in no-tree plots after the initial input to establish the trees in year one (Fig. 2a,b). Furthermore, the main work task in the tree plots changes from weeding to tree pruning, and the shady environment in the early months of crop establishment makes a more pleasant work environment. Experience with farmers suggests that they prefer, and are better able, to carry out a pruning regime than control persistent weeds such as para grass (*Brachiaria mutica*).



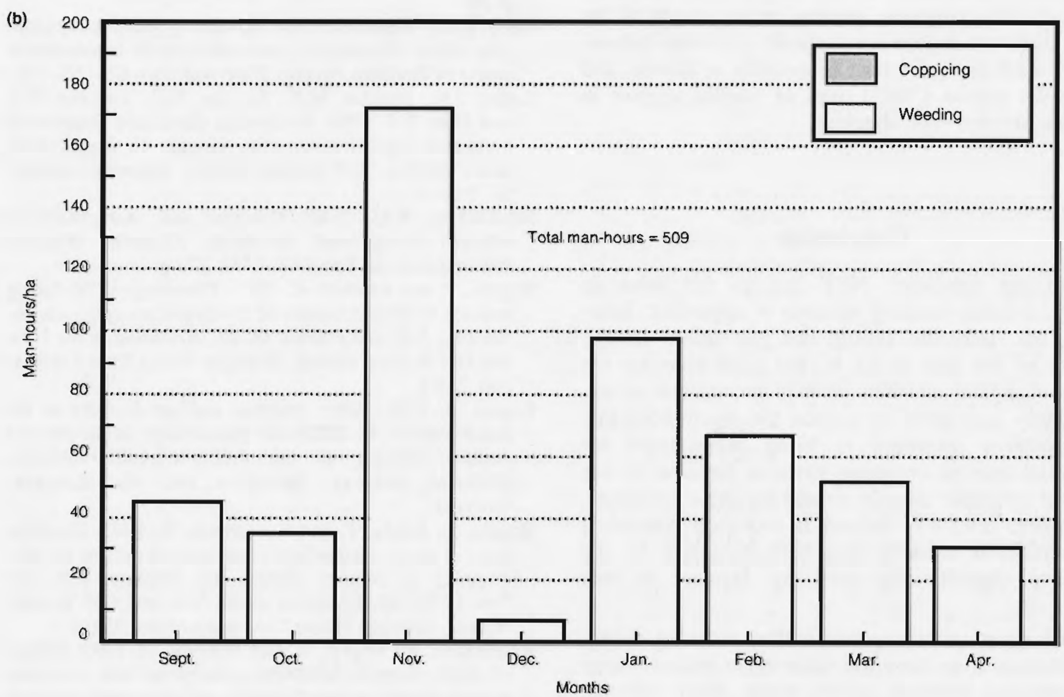


Fig. 2. Labour use profile 1993–94 season for (a) *Erythrina* and (b) no-tree plots.

Farmers generally have clear ideas about the products and services they want from trees on their farms. They are also aware of the adverse effects of tree competition on crop growth, and identify certain species which do not mix well in close association with food crops. Also, trees which produce prolific seed, grow rapidly, and are hard to cut, such as *Leucaena leucocephala*, can be positively disliked by farmers.

Attempts to introduce such competitive species into food cropping systems can result in, at best, farmer apathy and, at worst, serious conflict. In Western Samoa there is still ill-feeling in the farming community over the introduction of *Leucaena* for cocoa and coffee shade.

The tree species farmers readily associate with crops for service functions, such as shade, weed control and support, frequently share the following characteristics: they are easily propagated from stem cuttings or by direct seeding; they are softwood species easily cut with a bush knife; they have soft roots; they do not produce large amounts of seed; and they are easily killed by ring-barking close to the ground.

Species with these characteristics offer great flexibility because tree density and spatial arrangements can easily be adjusted to suit the particular cropping situation. Furthermore, pruning management of the trees does not require hard labour. *Erythrina subumbrans* used in food cropping systems in Samoa, and *Jatropha curcas* ('fiki') used as vanilla support in Tonga, are two such species.

Conclusion

Identifying candidate NFT species for roles in Pacific Islands farming systems is appealing; however, tree selection should not rest solely on the ability of the tree to fix N, but must consider the other attractive qualities already recognised in traditionally used trees. In Samoa the leguminous tree *Adenanthera pavonina* is being investigated for potential use in cropping systems because it has several products already valued by the community, but it does not fix N. Indeed, in root crop systems, it is considered unlikely that N-fixation will be the primary characteristic used by farmers in tree selection.

Perhaps of more importance than N-fixing ability, leguminous trees have the capacity to produce large amounts of biomass which make them valuable fallow species to put carbon (C) into Pacific Islands farming systems.

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References

Brook, R.M. 1992. Early results from an alley cropping experiment in the humid lowlands of Papua New Guinea. Nitrogen Fixing Tree Research Reports, 10. 73–76.

— 1993. Alley cropping for sweet potato in Papua New Guinea. Nitrogen Fixing Tree Research Reports, 11. 35–39.

Dixon, R.O.D. and Wheeler, C.T. 1983. Biochemical, physiological and environmental aspects of symbiotic nitrogen fixation. In: Gordon, W.C. and Wheeler, C.T. ed. Biological nitrogen fixation in forest ecosystems: foundations and applications. The Hague, Martinus Nijhoff/Junk. 108–172.

Garrity, D.P. and Mercado, A.R. 1994. Nitrogen fixation capacity in the component species of contour hedgerows: how important? Agroforestry Systems, 27. 241–258.

Hancock, I.R. 1989. Terminal Report, September 1985–February 1989. Dodo Creek Research Station, Research Department, Ministry of Agriculture and Lands, Solomon Islands.

Hussain, A., Hussain, A., Hayee, M.A. and Nasir, M. 1988. The leaves of leguminous trees as nutrients for agricultural crops. Nitrogen Fixing Tree Research Reports, 6. p. 20.

Kang, B.T., Wilson, G.F. and Sipkens, L. 1981. Alley cropping maize (*Zea mays* L.) and leucaena (*L. leucocephala* Lam.) in Southern Nigeria. Plant and Soil, 63. 165–179.

Ladha, J.K., Peoples, M.B., Garrity, D.P., Capuno, V.T. and Dart, P.J. 1993. Estimating dinitrogen fixation of hedgerow vegetation using the nitrogen-15 natural abundence method. Soil Science Society American Journal, 57. 732–737.

MacDicken, K.G. 1994. Selection and mangement of nitrogen fixing trees. Mortilton, Arkansas, Winrock International and Bangkok, FAO. 272 p.

Nygren, P. and Ramirez, C. 1993. Phenology of N_2-fixing nodules in pruned clones of *Erythrina poeppigiana*. In: Westley, S.B. and Powell, M. ed., *Erythrina* in the New and Old Worlds. Hawaii, Nitrogen Fixing Tree Association. 358 p.

Rogers, S. 1995. Alley cropping and agroforestry in the South Pacific. In: IBSRAM Proceedings of the Second Annual Meeting of the *PACIFICLAND* Network. IBSRAM Network Document No. 10. Bangkok, Thailand.

Rogers, S., Iosefa, T. and Rosecrance, R. 1993. Development of an *Erythrina*-based agroforestry system for taro cropping in Western Samoa. In: Westley, S.B. and Powell, M., ed. *Erythrina* in the New and Old Worlds. Hawaii, Nitrogen Fixing Tree Association. 358 p.

Rosecrance, R., Rogers, S. and Tofinga, M. 1992. Effects of alley cropped *Calliandra calothyrsus* and *Gliricidia sepium* hedges on weed growth, soil properties, and taro yields in Western Samoa. Agroforestry Systems, 19. 57–66.

Tekle-Halmanot, A., Weeraratna, C.S. and Doku, E.V. 1991. Evaluation of three tree legume species in Western Samoa. Nitrogen Fixing Tree Research Reports, 9. 71–74.

Weeraratna, C.S. and Asghar, M. 1992. Effects of grass and dadap mulches on some soil (an Inceptisol) properties and yield of taro (*Colocasia esculenta*) in Western Samoa. Tropical Agriculture (Trinidad), 69. 83–87.

Yamoah, C.F., Agboola, A.A. and Wilson, G.F. 1986. Nutrient contribution and maize performance in alley cropping systems. Agroforestry Systems, 4. 247–254.

Young, A. 1976. Tropical Soils and Soil Survey. Cambridge University Press, London. 468 p.

— 1989. Agroforestry for Soil Conservation. Wallingford, Oxon, CAB International. 276 p.